Seebeck Nanoantennas for Solar Energy Harvesting

Javier González

Universidad Autónoma de San Luis Potosi

San Luis Potosi, SLP

Mexico

Outline

- Introduction to Nanoantennas (How everything started).
- Antenna-coupled microbolometers.
- Applications to Solar Energy Harvesting.
    - Rectennas.
    - Antenna-coupled thermocouples.
    - Seebeck Nanoantennas.
- Other Applications.
- Conclusions.

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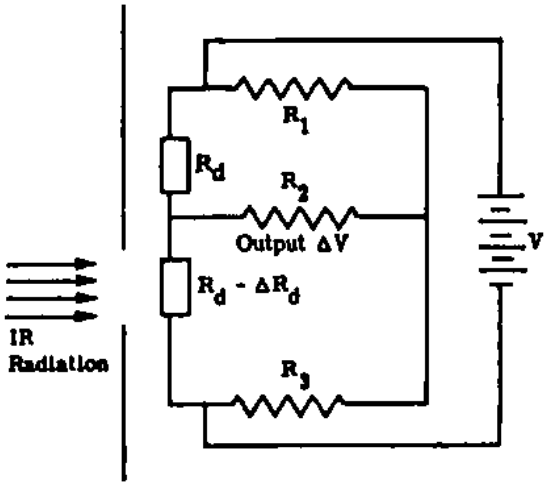
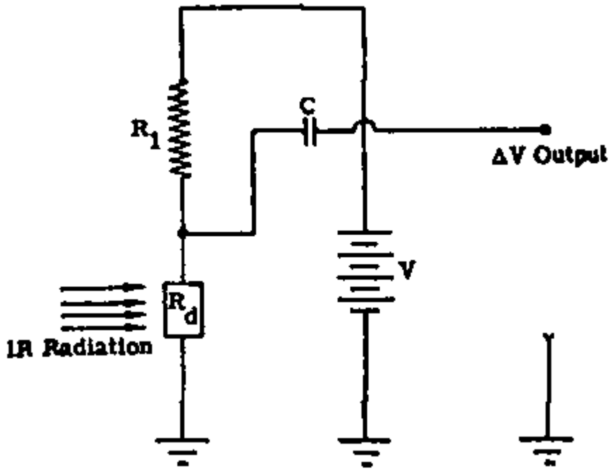
Introduction

Bolometers

- Made of materials with very small thermal capacity and large temperature coefficient of resistance so that the absorbed radiation produces a large change in resistance.
- They are operated by passing a bias current through the detector and monitoring the output voltage.

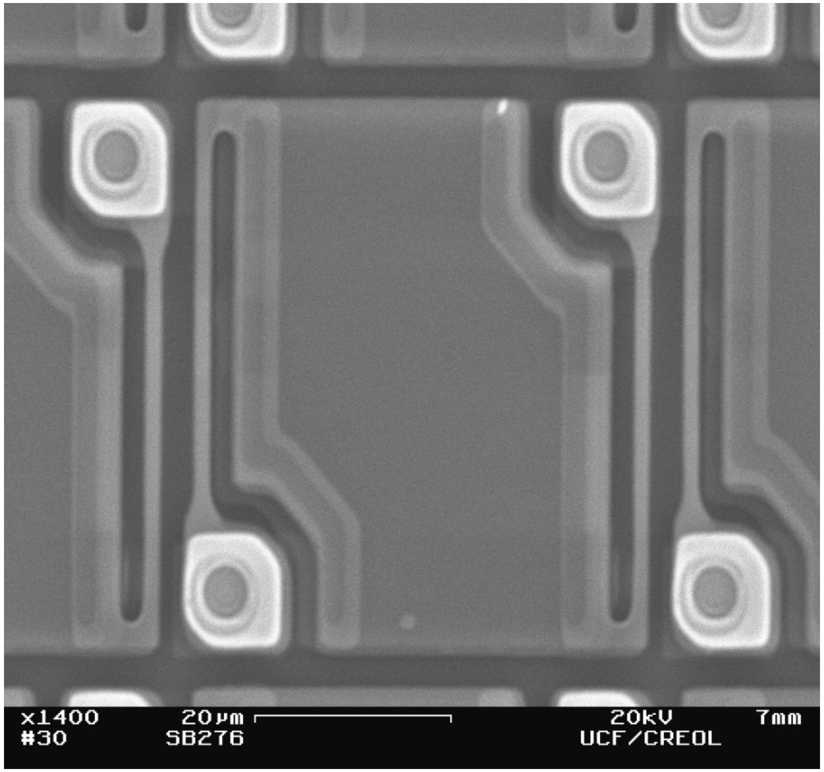


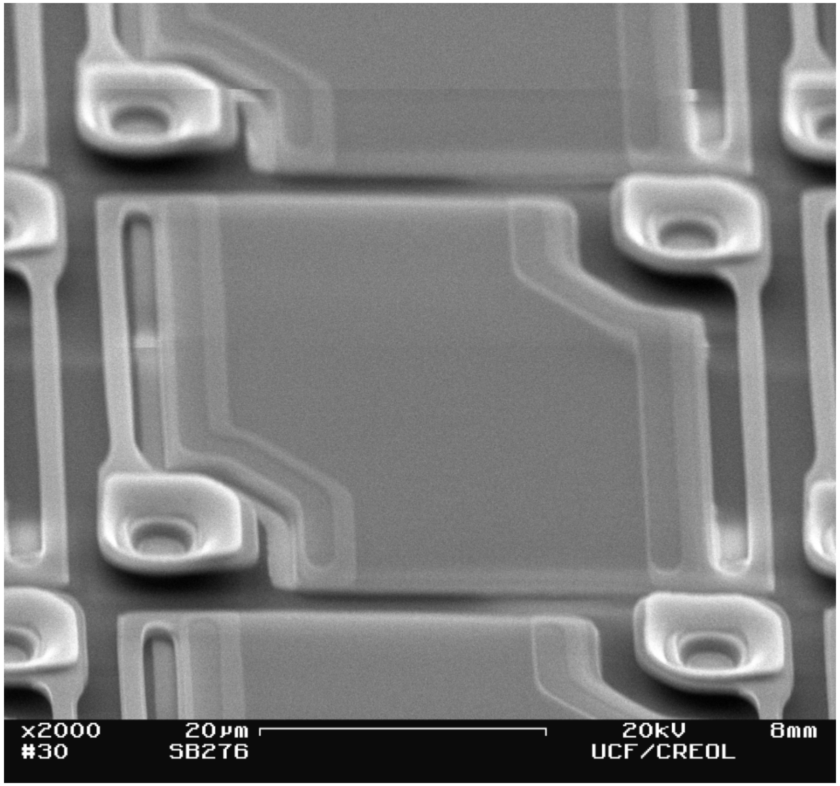
Bolometer Detector Circuit with bridge configuration for dc operation.



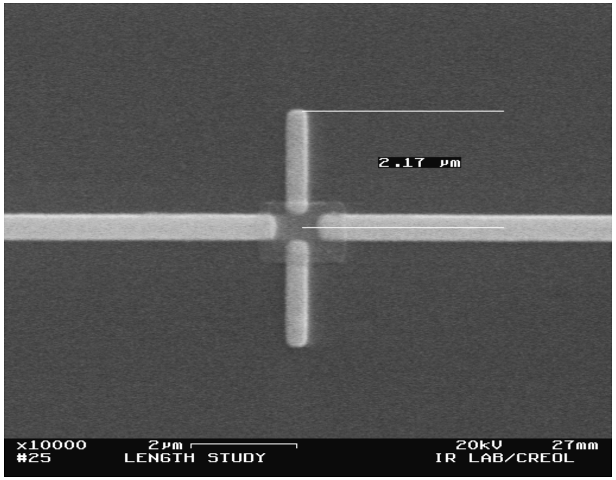
AC-coupled Bolometer Detector Circuit

Microbolometers

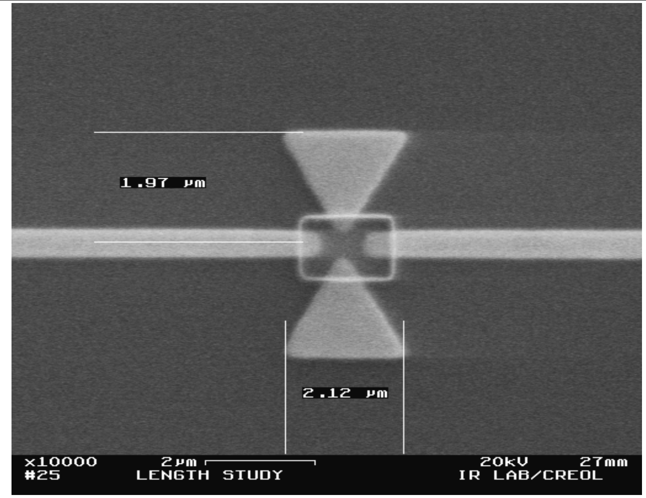




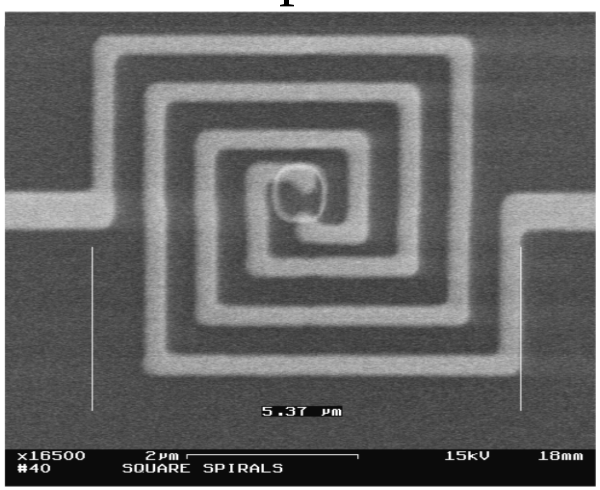
Antenna-coupled microbolometers



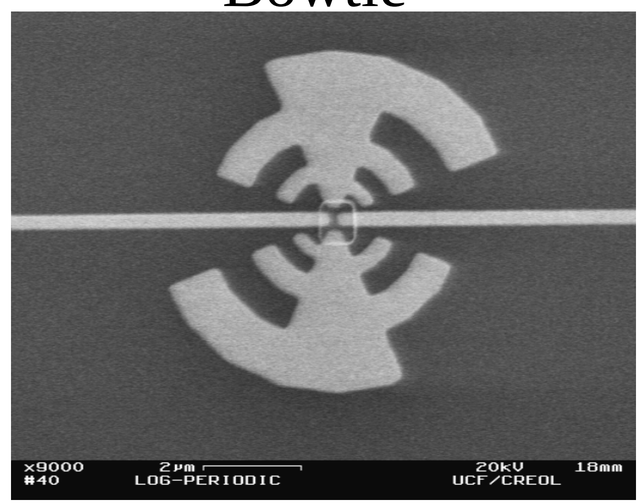
Dipole



Bowtie



Square-Spirals



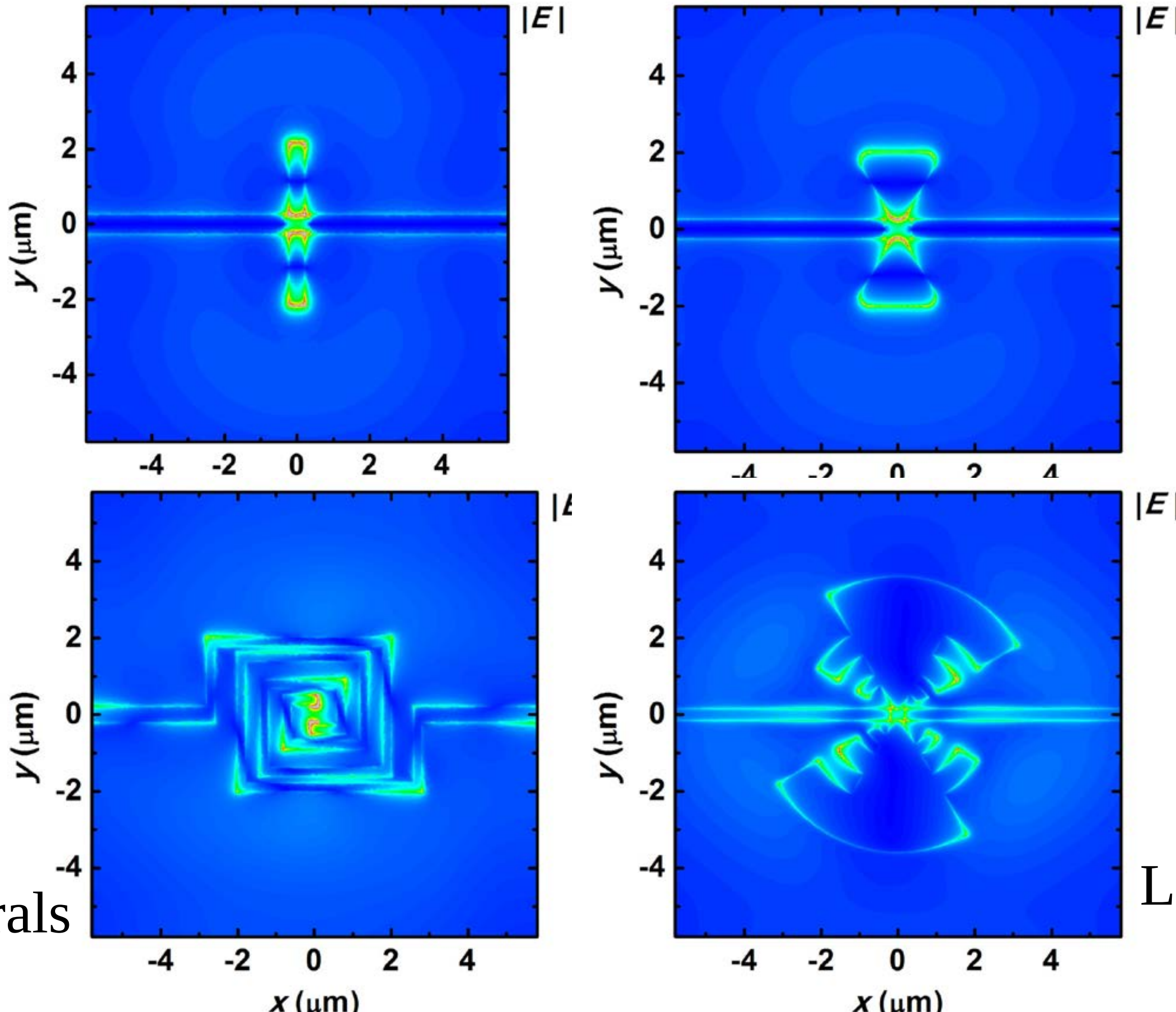
Log-Periodic

F.J. González, G.D. Boreman, “Comparison of Dipole, Bowtie, Spiral and Log-periodic IR Antennas”, *Infrared Physics and Technology*, vol. 46, no. 5, (2005), 418-428.

Antenna-coupled microbolometers

Dipole

Bowtie

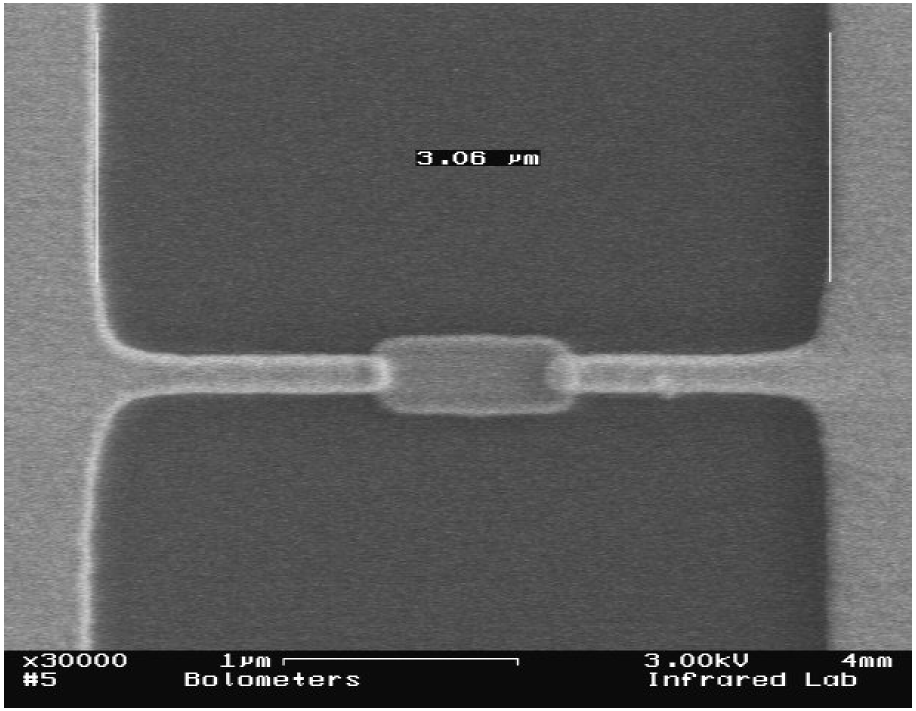


Square-Spirals

Log-Periodic

F. J. Gonzalez, E. Briones, E. Tucker, G. Boreman, M. Raschke, “Electric Near-Field Distribution of Optical Nanoantennas”, Frontiers in Optics/Laser Science XXIX (FiO/LS), October 2013, Orlando, Florida.

Cambridge EBMF 10.5/CS Electron Beam Lithography System



Microbolometer fabricated using EBL
The sensitive element is a NB patch of 800 nm × 200 nm

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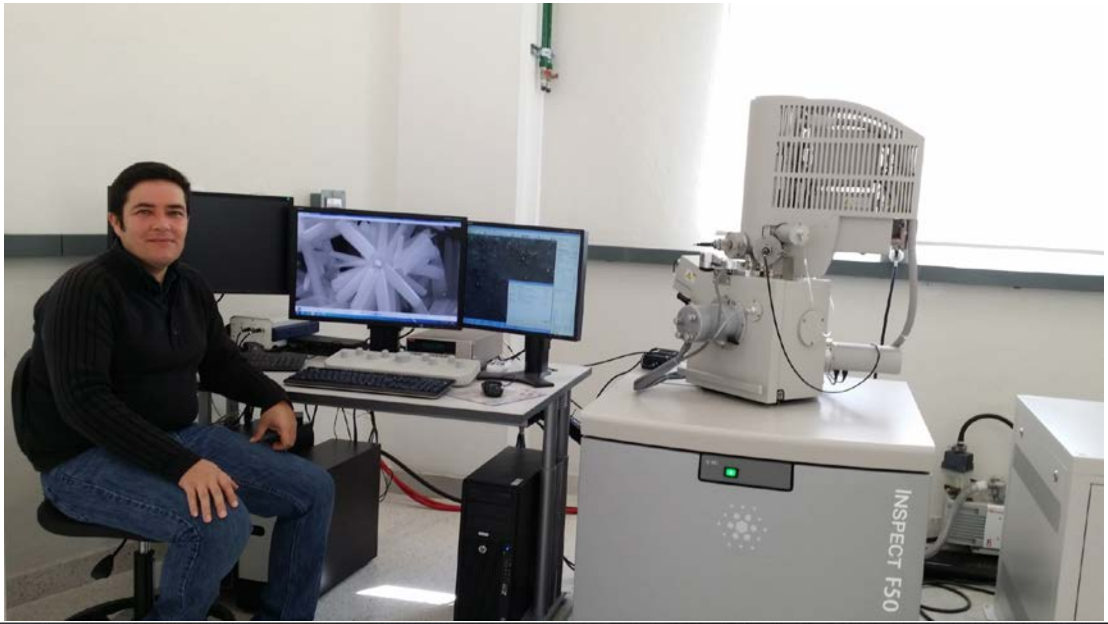
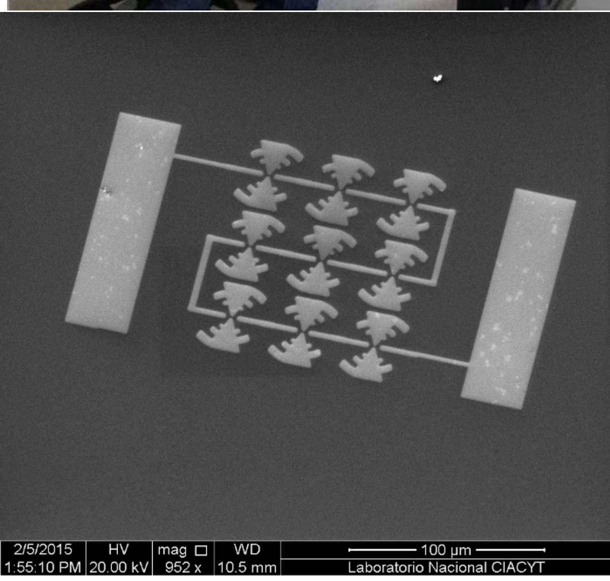
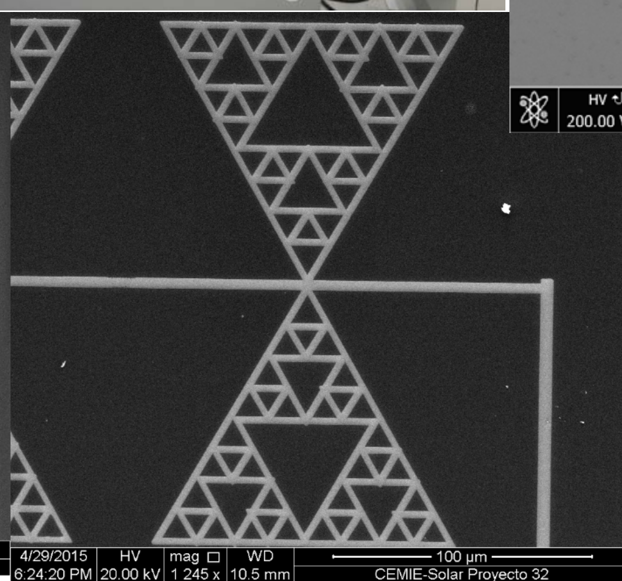
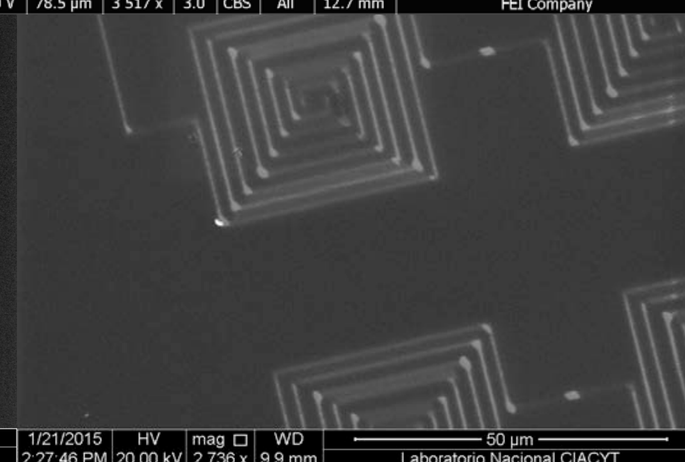
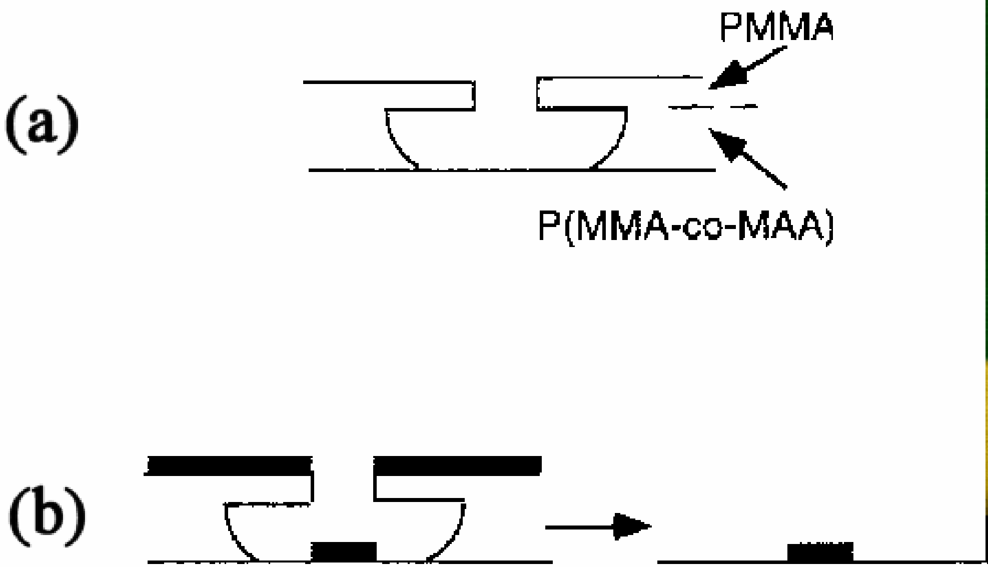




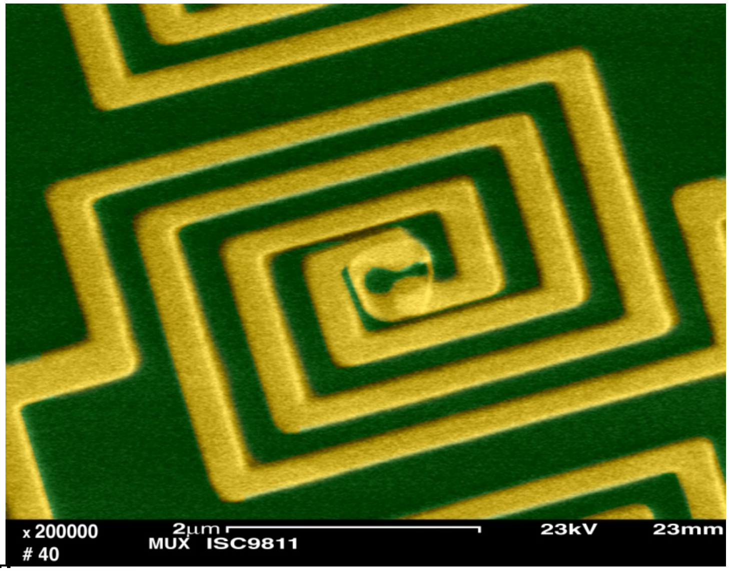




Liftoff



Bilayer Profile



Finished Device

Characterization

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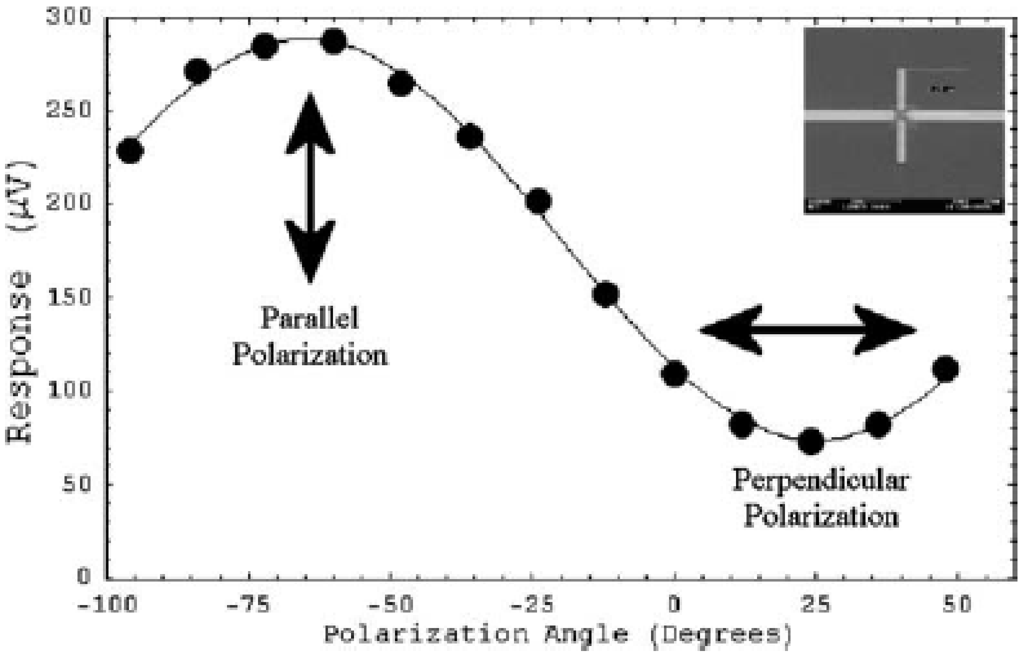
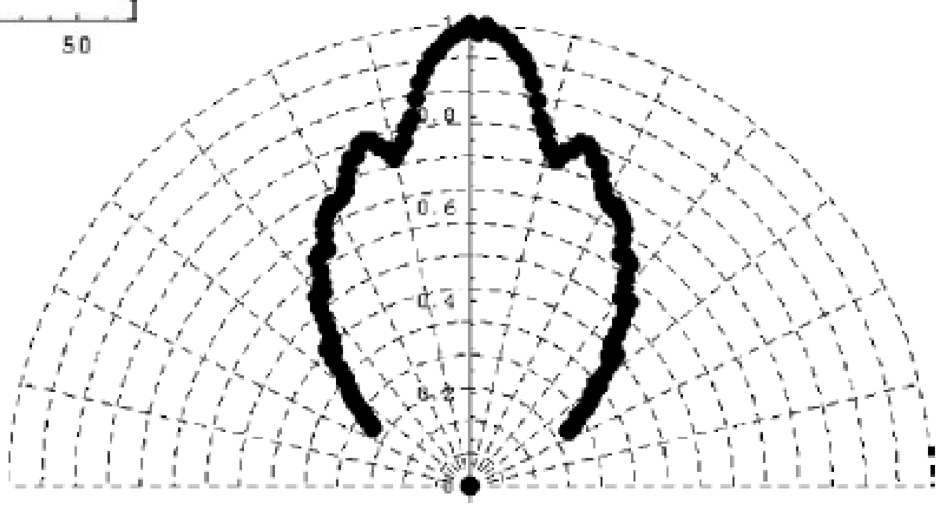
Characterization

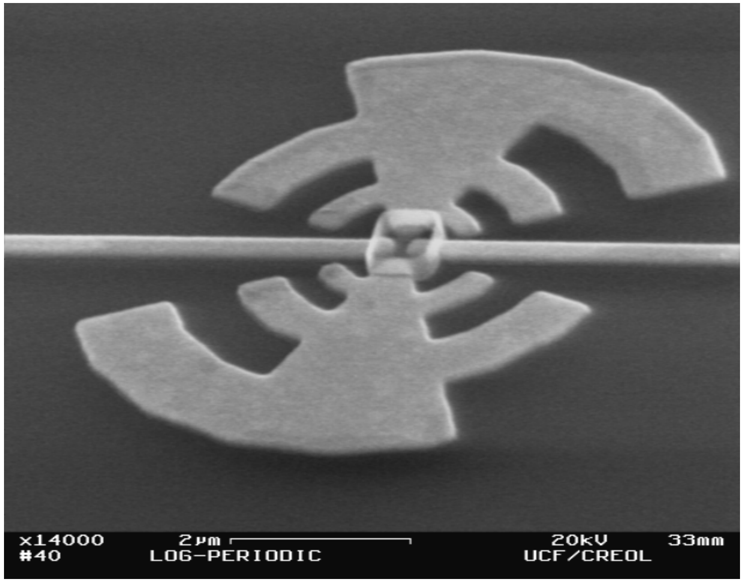
Antenna Measurements

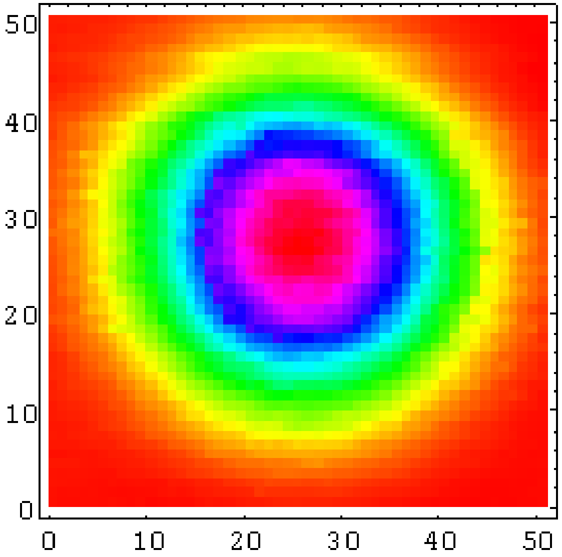


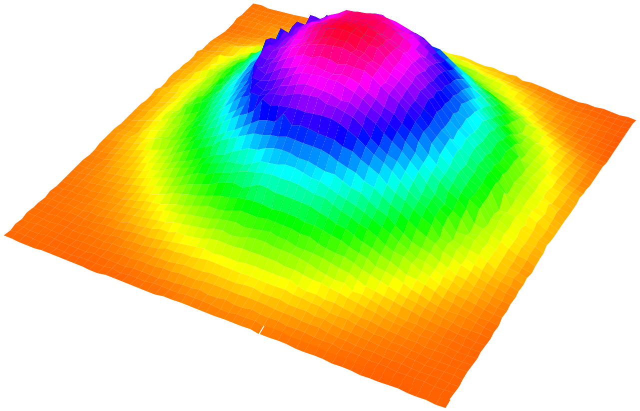
F.J. González, G.D. Boreman, "Comparison of Dipole, Bowtie, Spiral and Log-periodic IR Antennas", *Infrared Physics and Technology*, vol. 46, no. 5, (2005), 418-428.



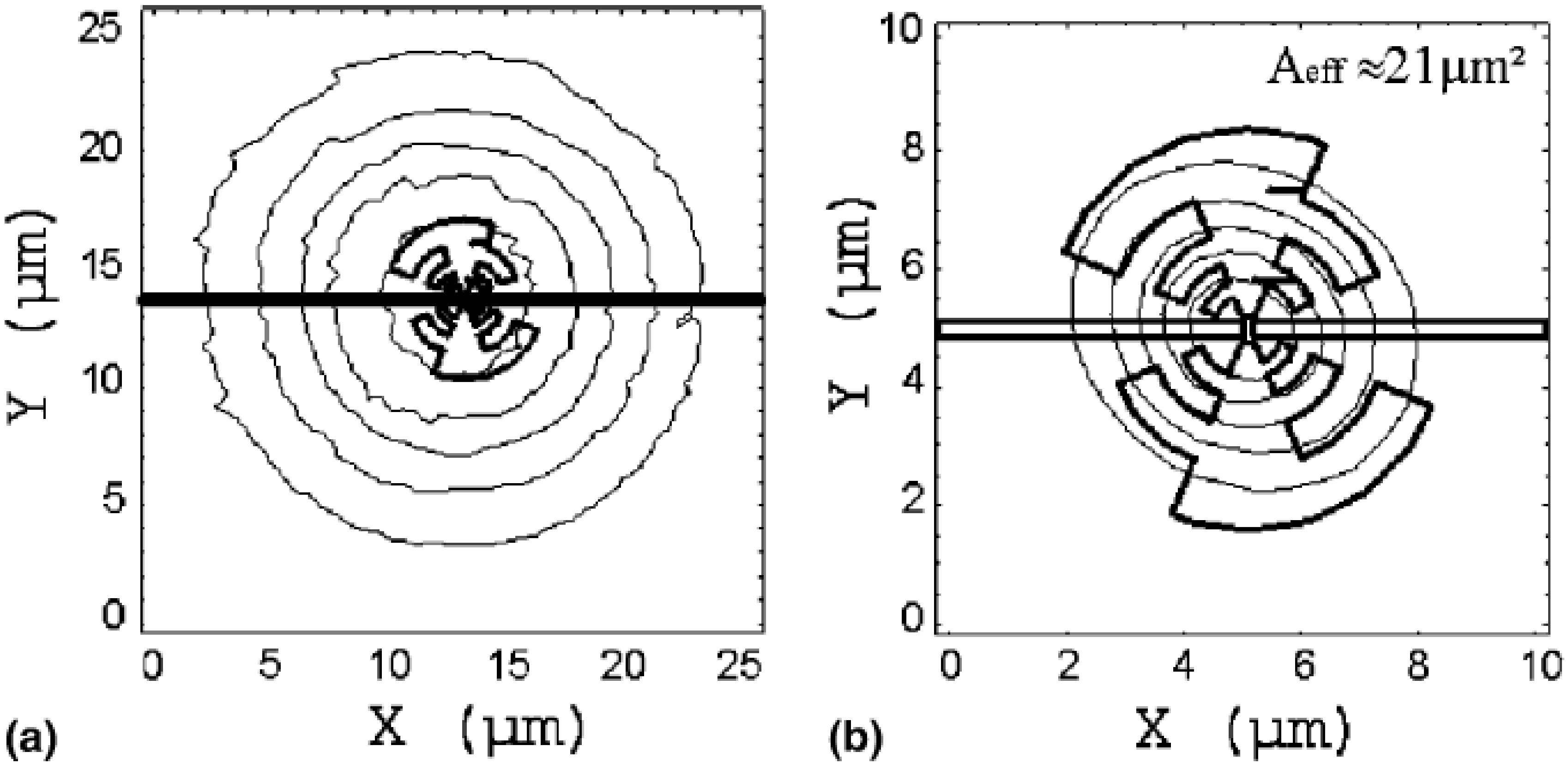
2D Scan in the Infrared







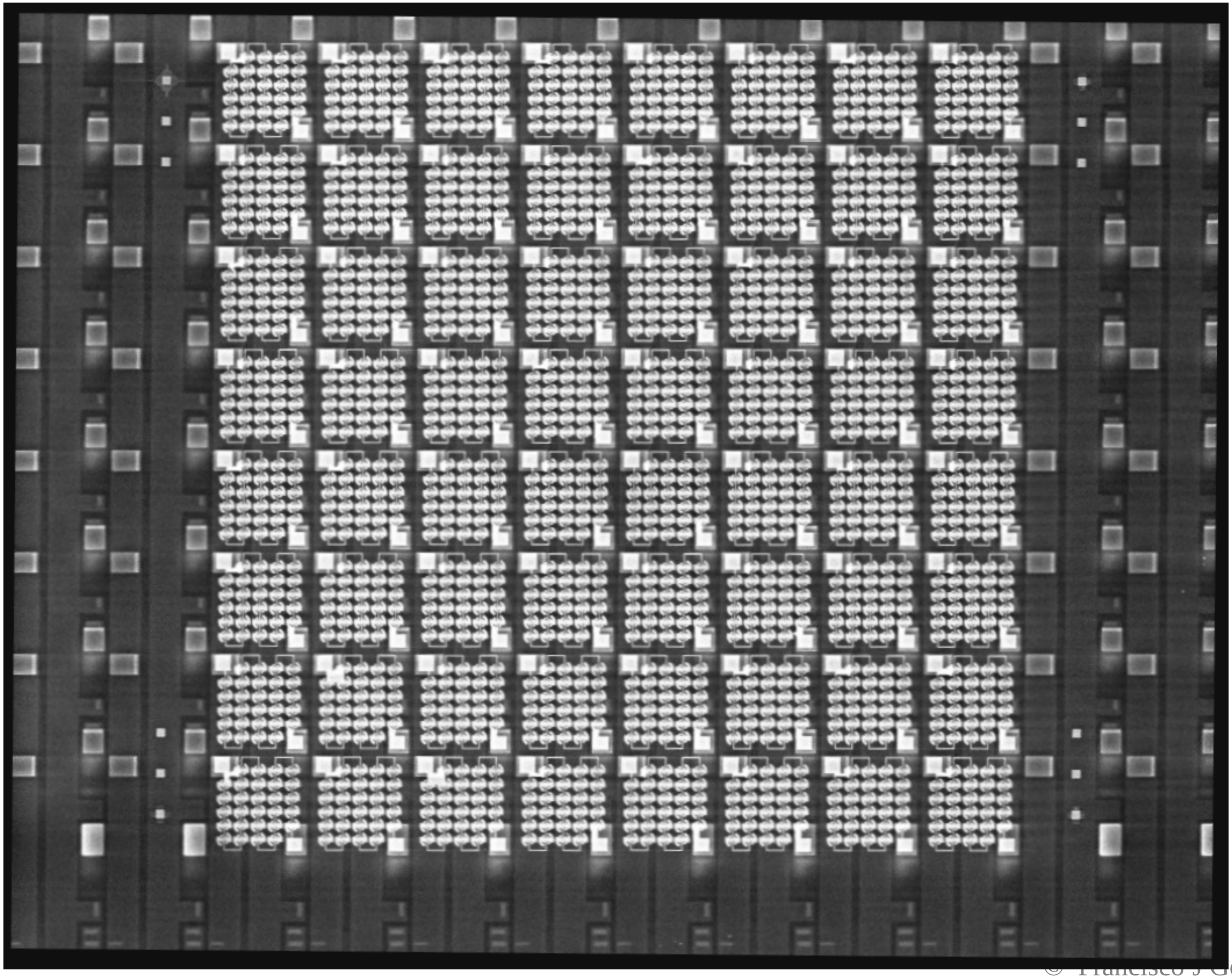
Deconvolution



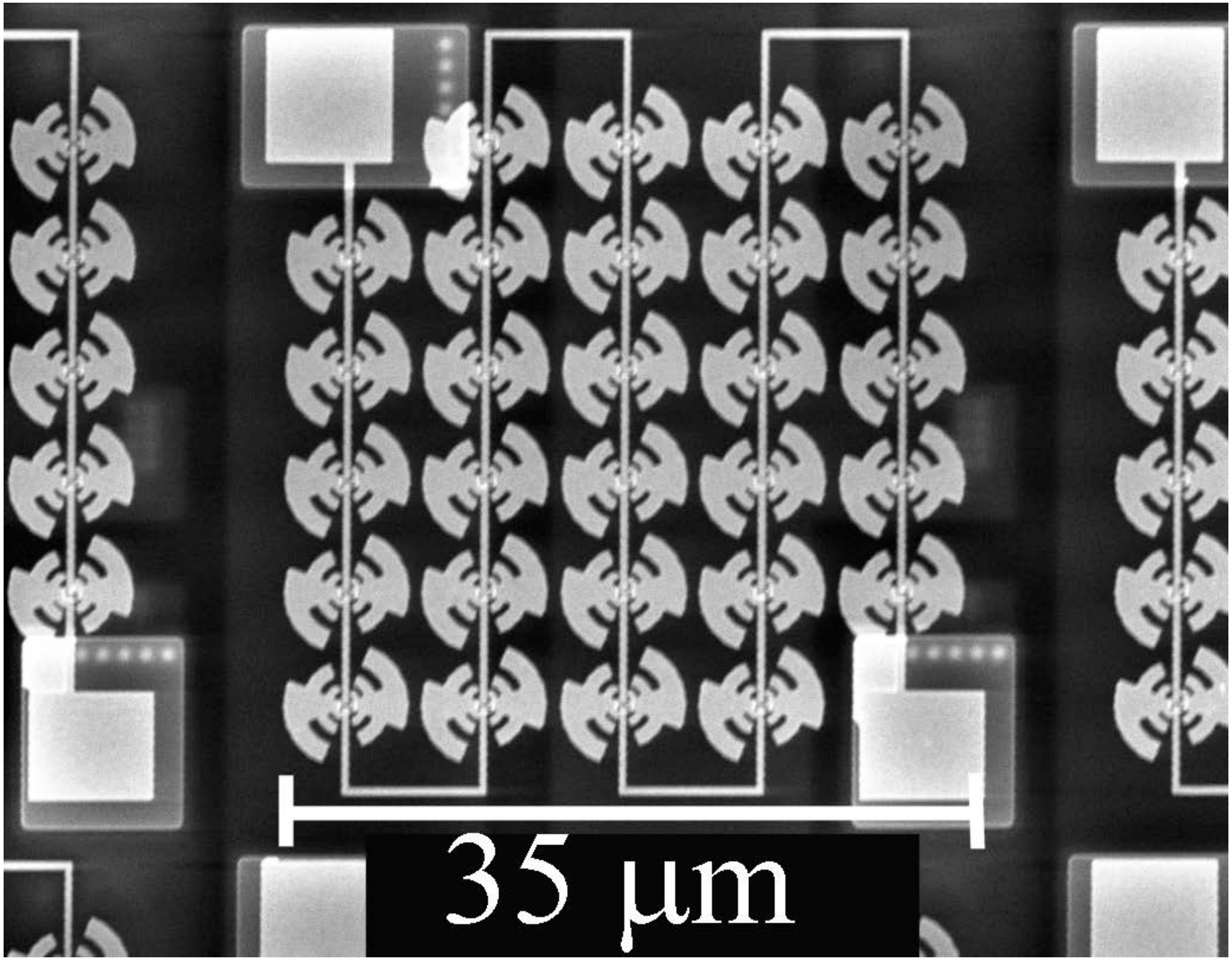
F.J. González, G.D. Boreman, "Comparison of Dipole, Bowtie, Spiral and Log-periodic IR Antennas", *Infrared Physics and Technology*, vol. 46, no. 5, (2005), 418-428.

Integration to ROICs

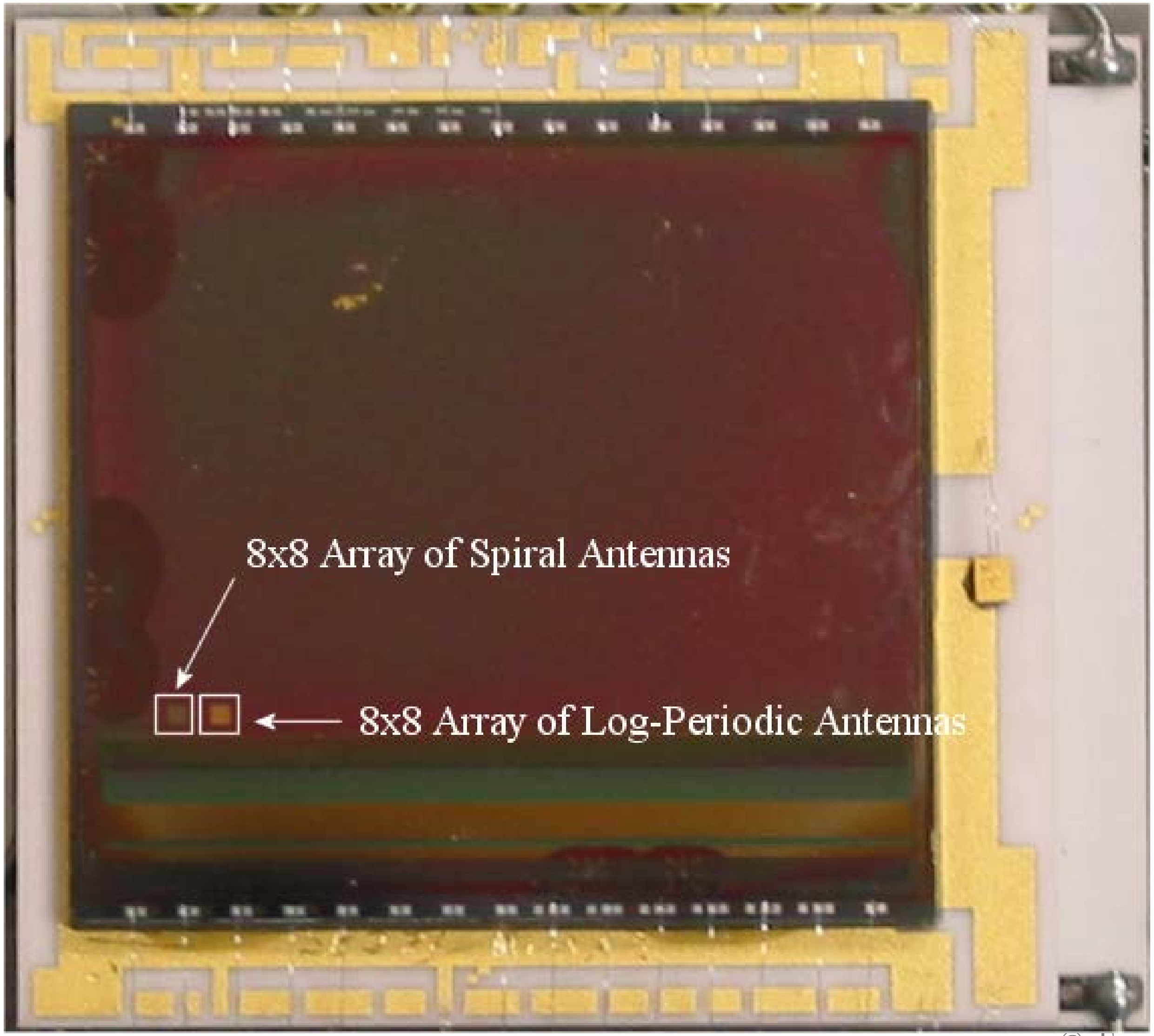
Integration to ROIC's



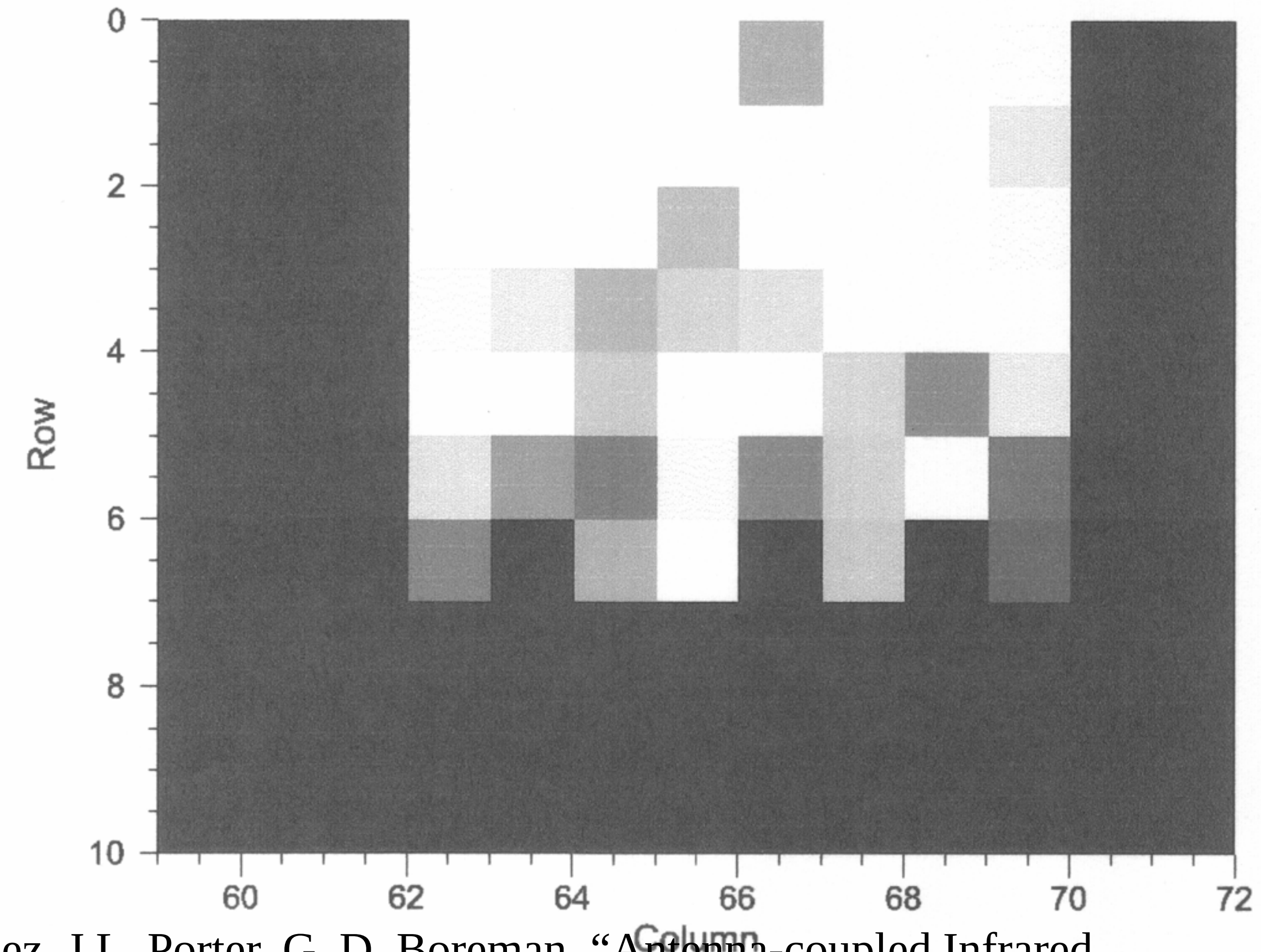
Integration to ROIC's



Integration to ROIC's



Integration to ROIC's



F.J. González, J.L. Porter, G. D. Boreman, "Antenna-coupled Infrared Focal Plane Array", *Microwave and Optical Technology Letters*, Vol. 48 No. 1, (2006), 165-166.

Applications to
Solar Energy Harvesting

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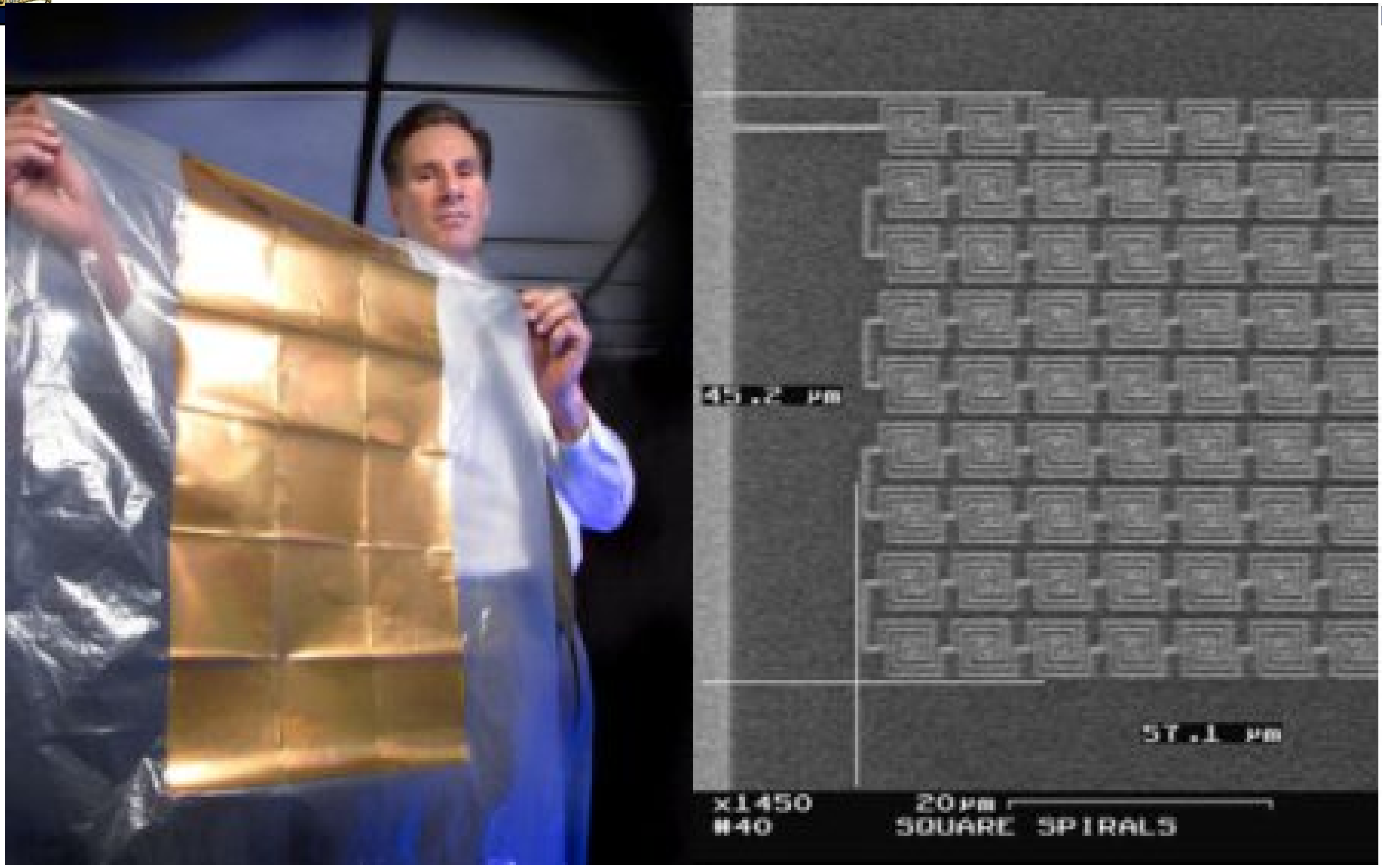
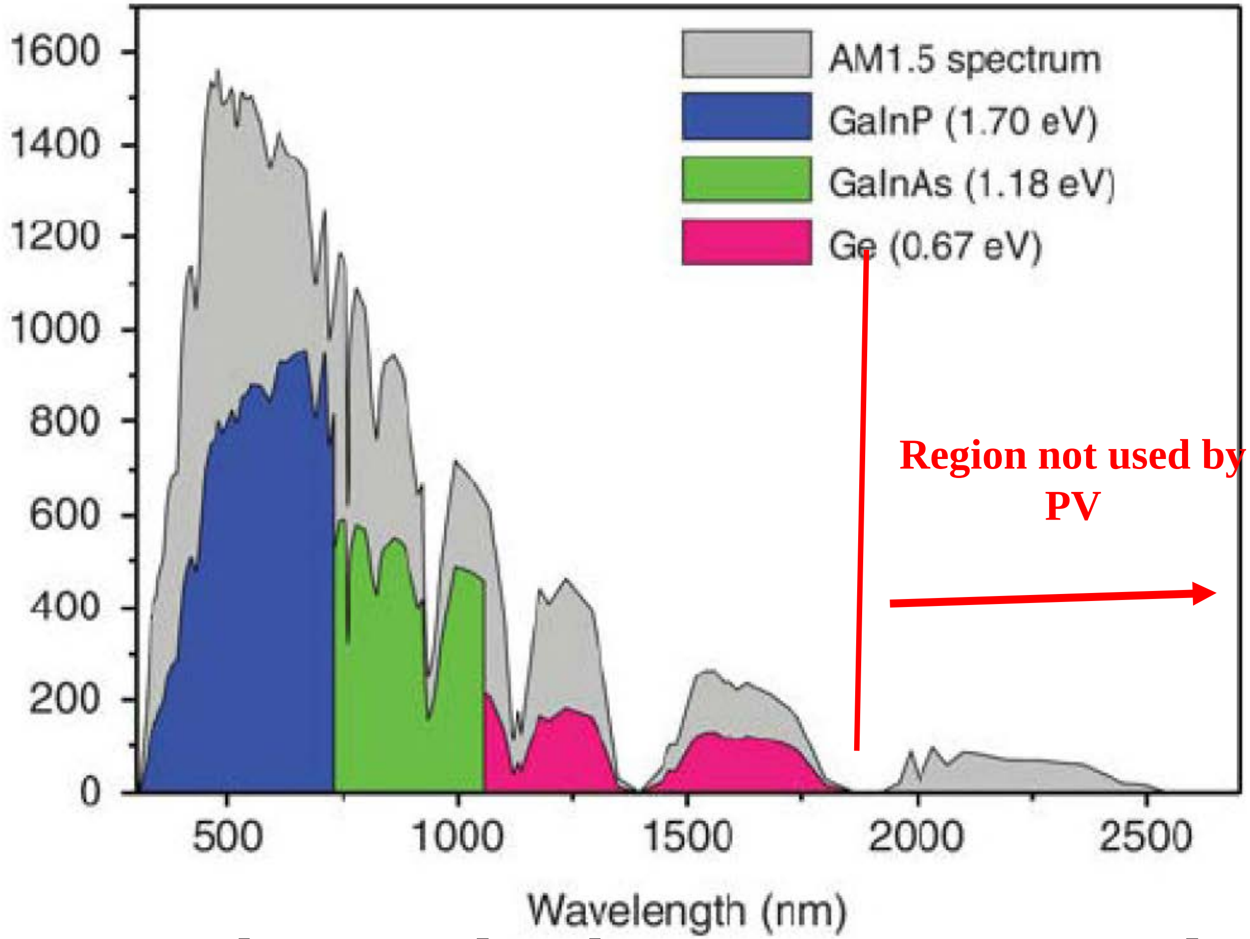
Advantages



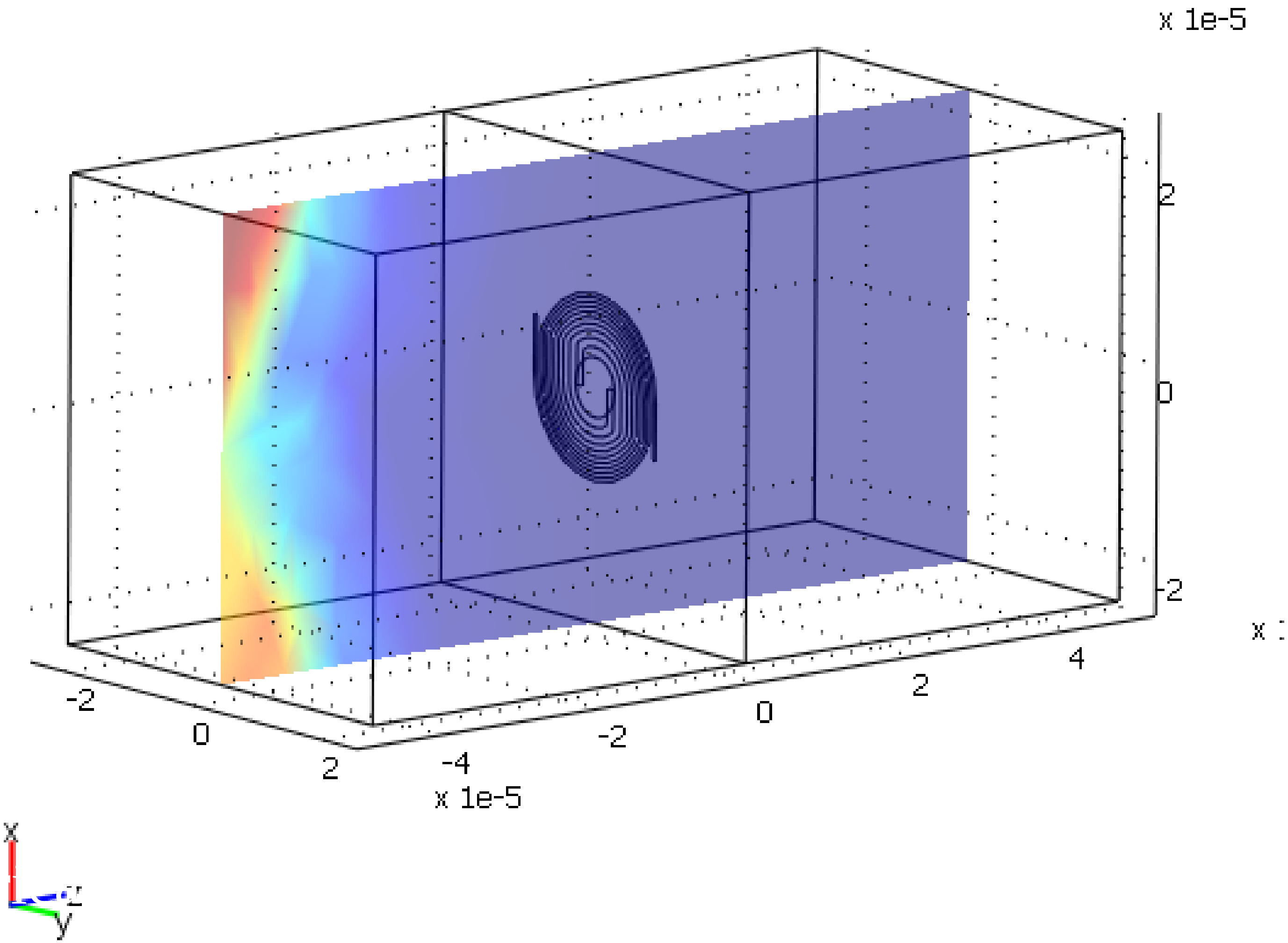
Array of nanoantennas can be fabricated on flexible substrates and placed on clothing or rolls that can later be extended for charging portable equipment.

Advantages

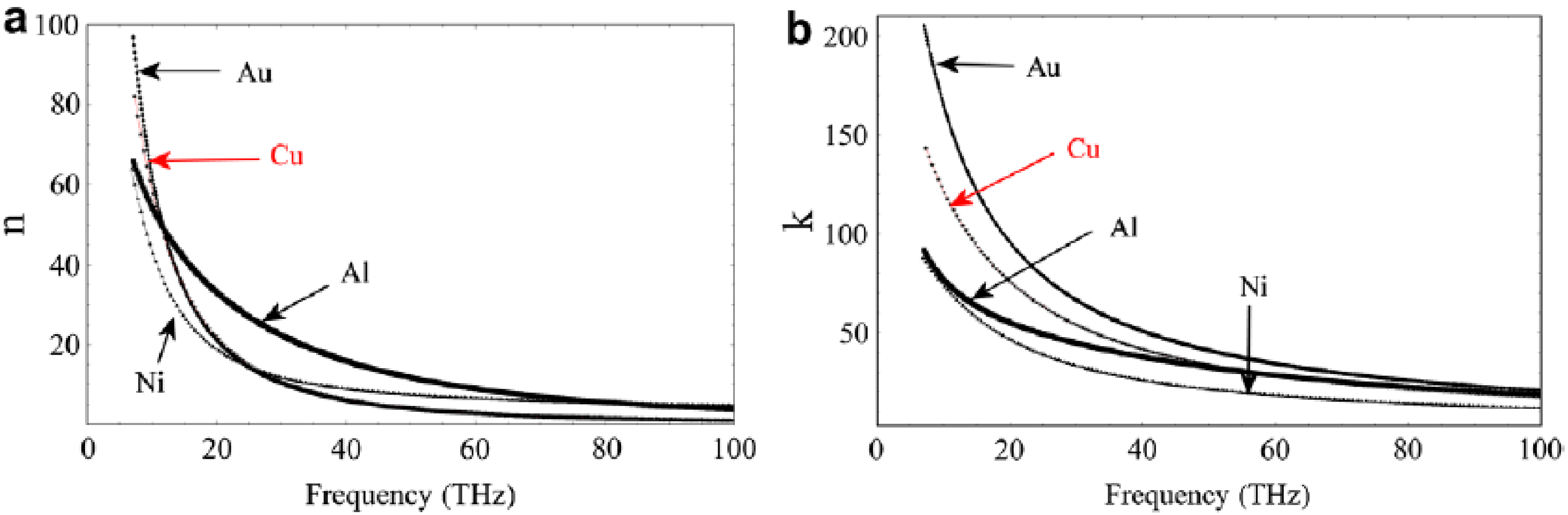


Nanoantennas can be tuned to harvest energy at infrared and longer wavelengths, which are not used by PV.

FEM Simulations



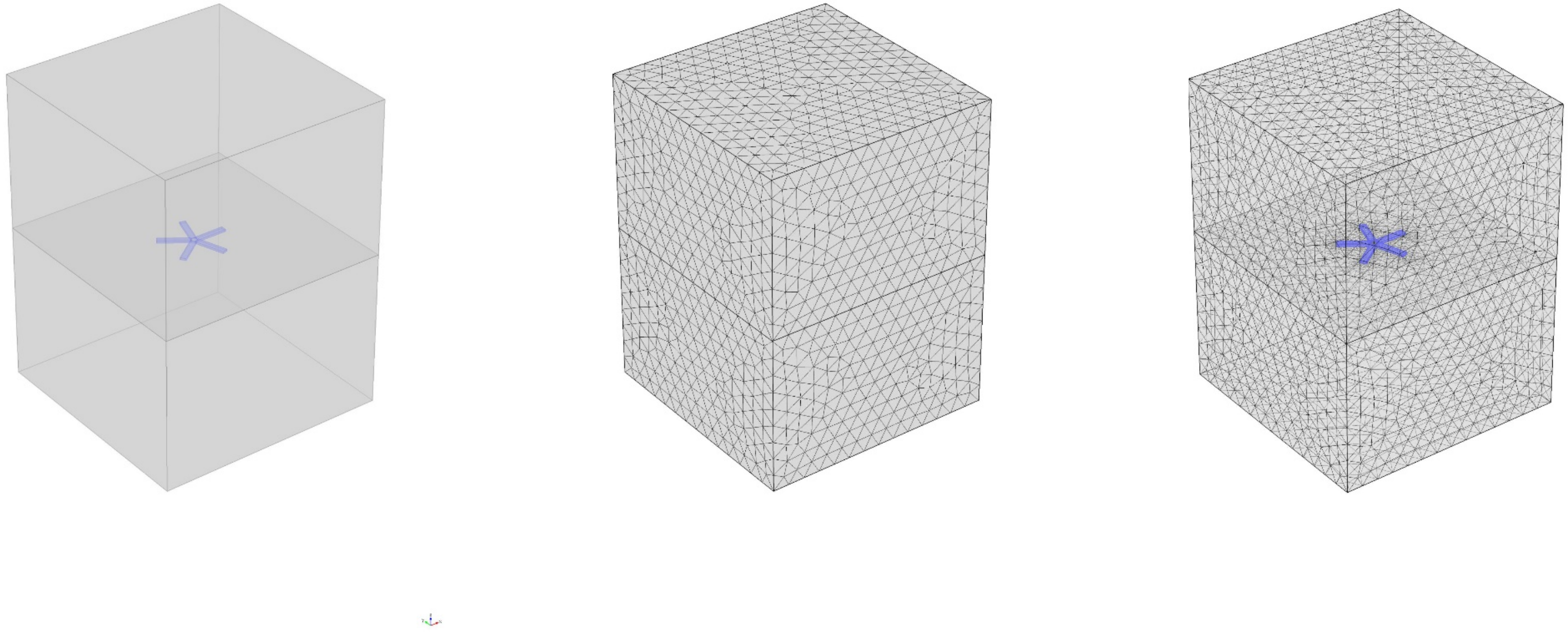
Material Parameters



n and *k* values for gold, aluminum, copper and nickel films as a function of frequency obtained using a J.A. Woollam infrared variable angle spectroscopic ellipsometer (IR-VASE).

F.J. González, J. Alda, J. Simón, J. Ginn and G. Boreman, “The effect of metal dispersion on the resonance of antennas at infrared frequencies”, *Infrared Physics and Technology, vol. 52, No. 1, (2009), 48–51*.

FEM Simulations



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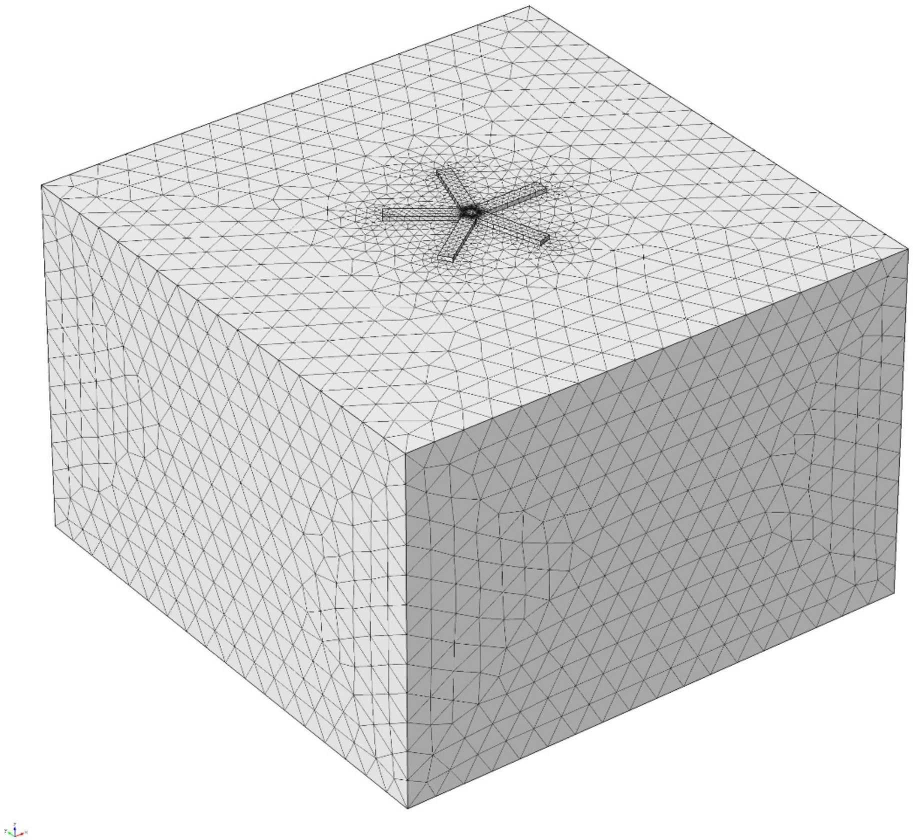
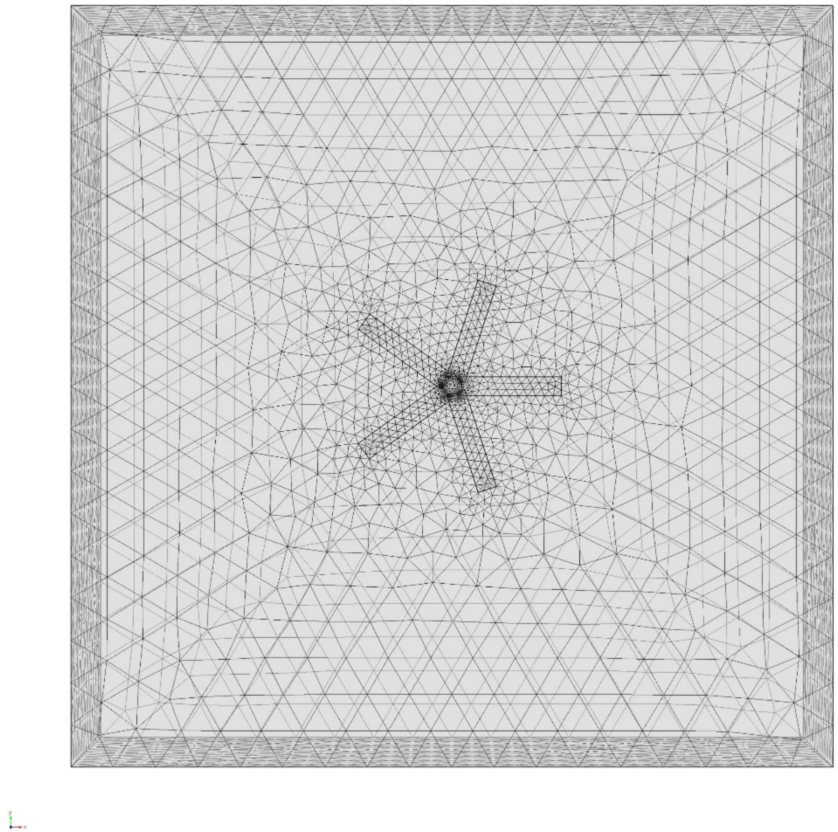
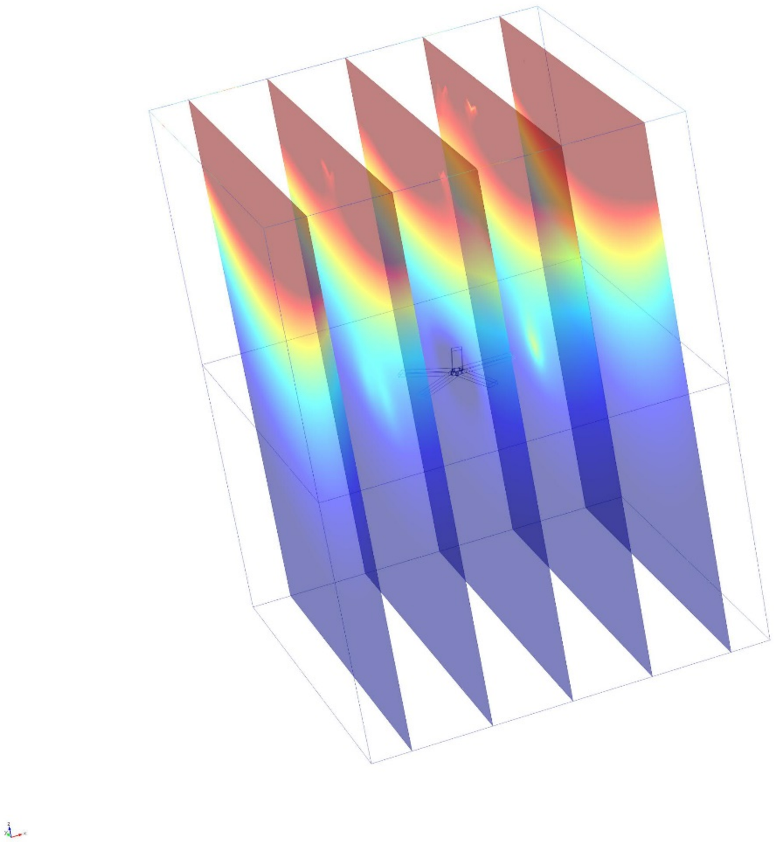
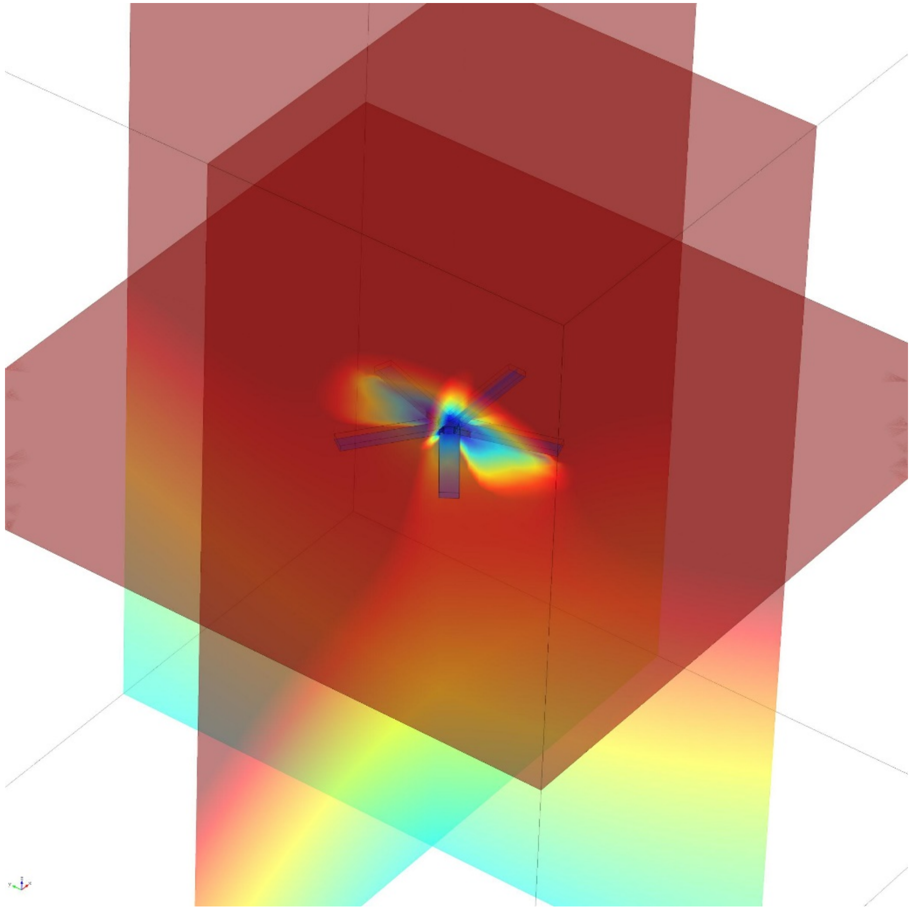


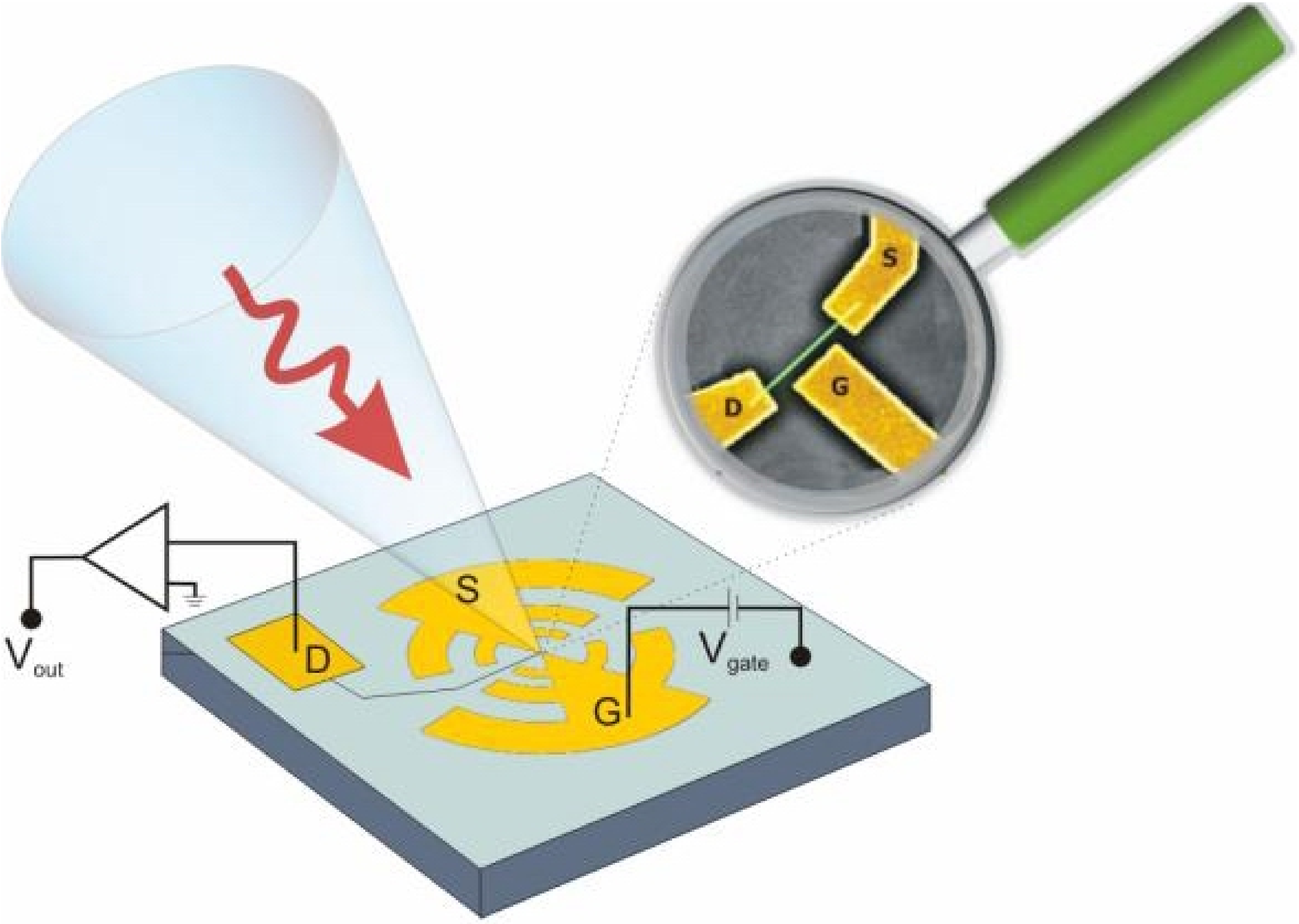


FEM Simulations





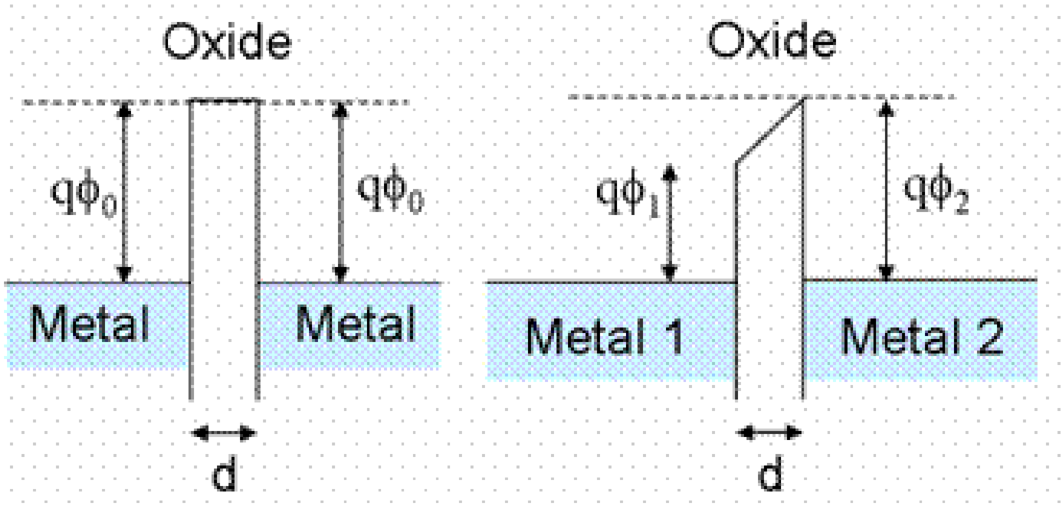
Detection Mechanism



Harvesting mechanism

Rectennas

MOM Diodes



Rectification Mechanism ➔ MOM Diodes

- Low efficiency
- High impedance, which creates an impedance missmatch with the antenna reducing its efficiency.
- Efficiency in the 10^{-6}-10^{-9}.

E. Briones, J. Alda and **F. J. González,** "Conversion efficiency of broad-band rectennas for solar energy harvesting applications", *Optics Express, (21) S3, pp. A412–A418, (2013).*

Seebeck Nanoantennas

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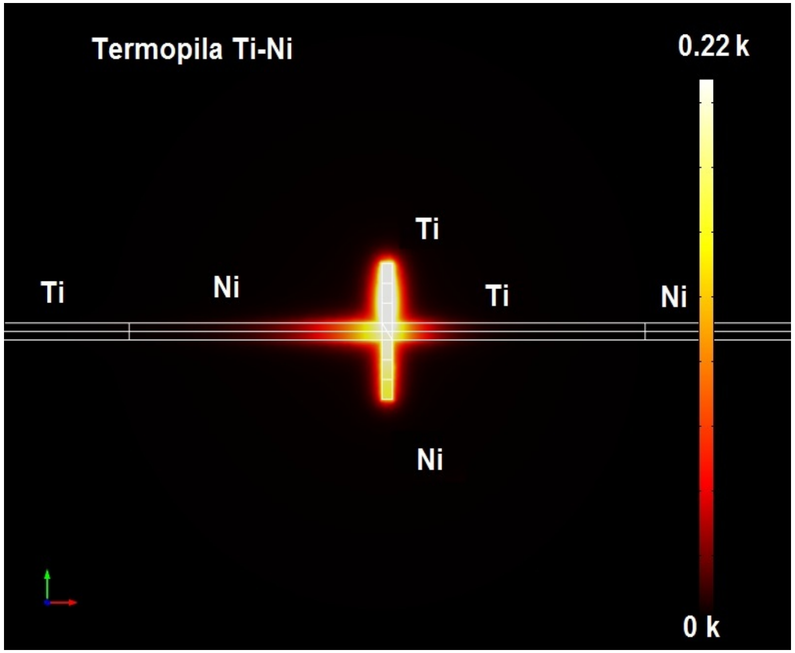
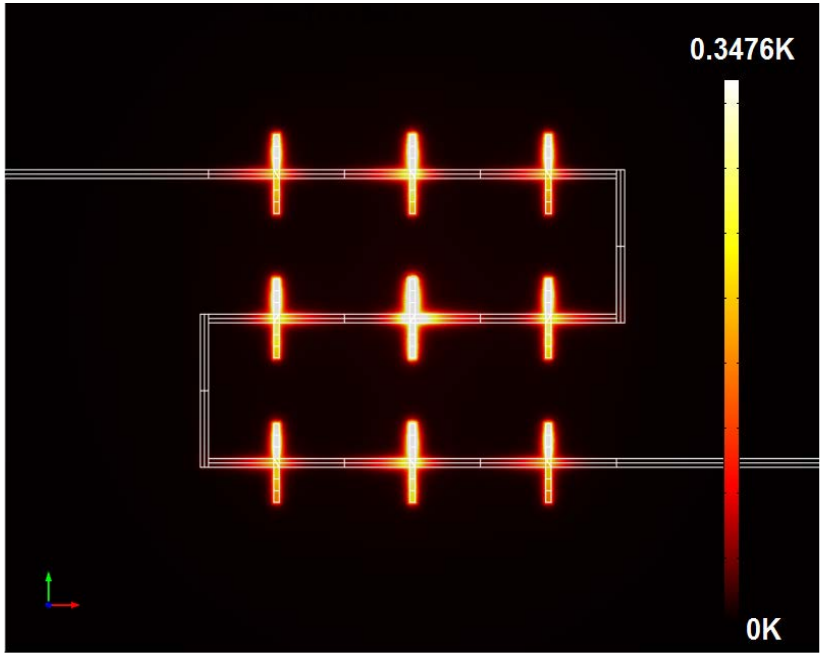
Single element nanoantenna



Array of Nanoantennas



Materials: **Ti/Ni** **(**S_Ni = -15, S_Ti =7.19)

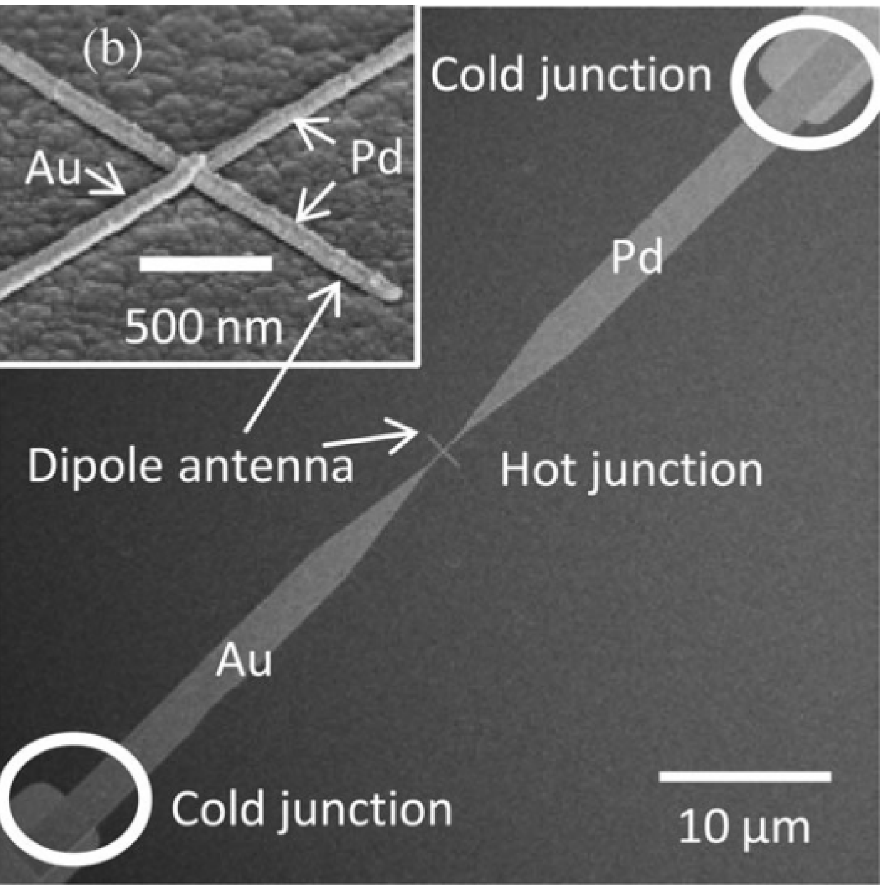
→ **$\Delta V = 3.6\mu V$**

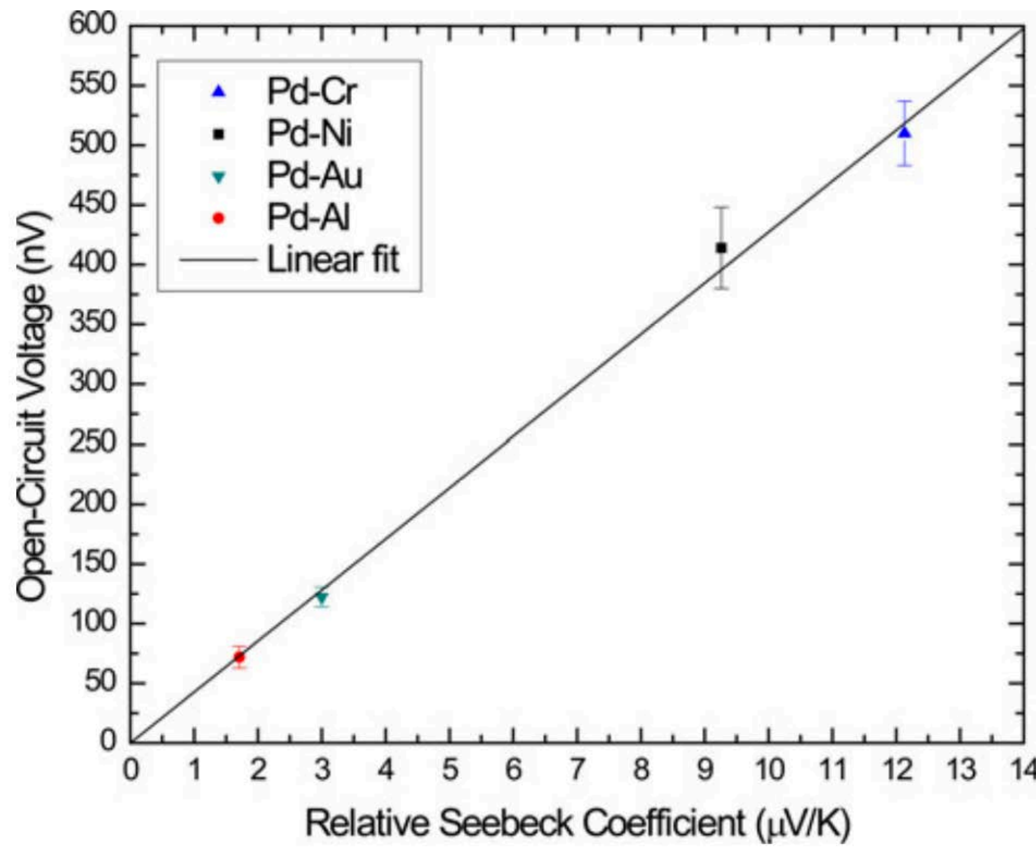
Signal increase by using an array

→ **$\Delta V = 26\mu V$**

Antenna-coupled Thermocouples

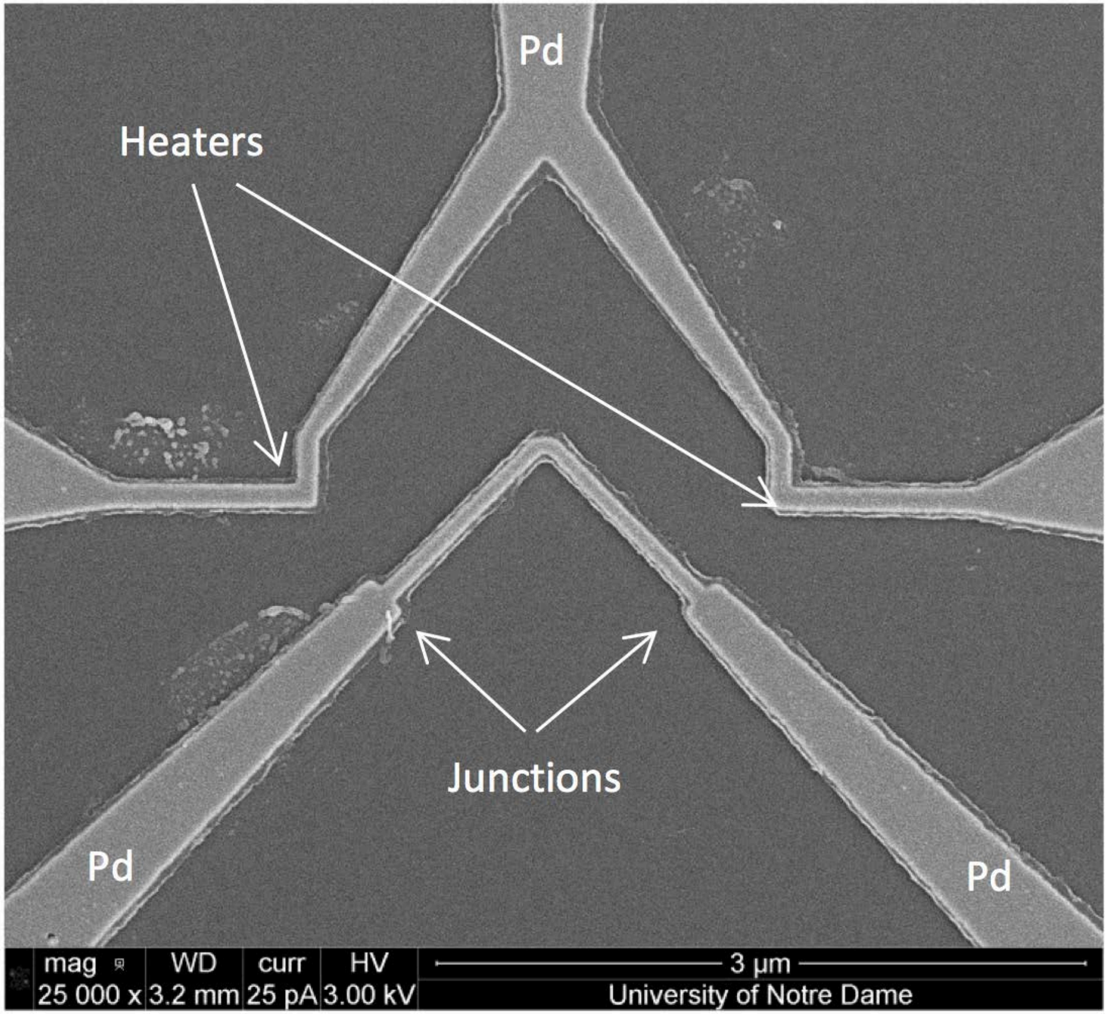
- Nanorectennas are actually thermocouples (Reference) .





G.P. Szakmany, P.M. Krenz, A.O. Orlov, G.H. Bernstein, W. Porod, “Antenna-Coupled Nanowire Thermocouples for Infrared Detection,” IEEE Transactions on Nanotechnology, 12 (2), pp. 163-167, (2013).

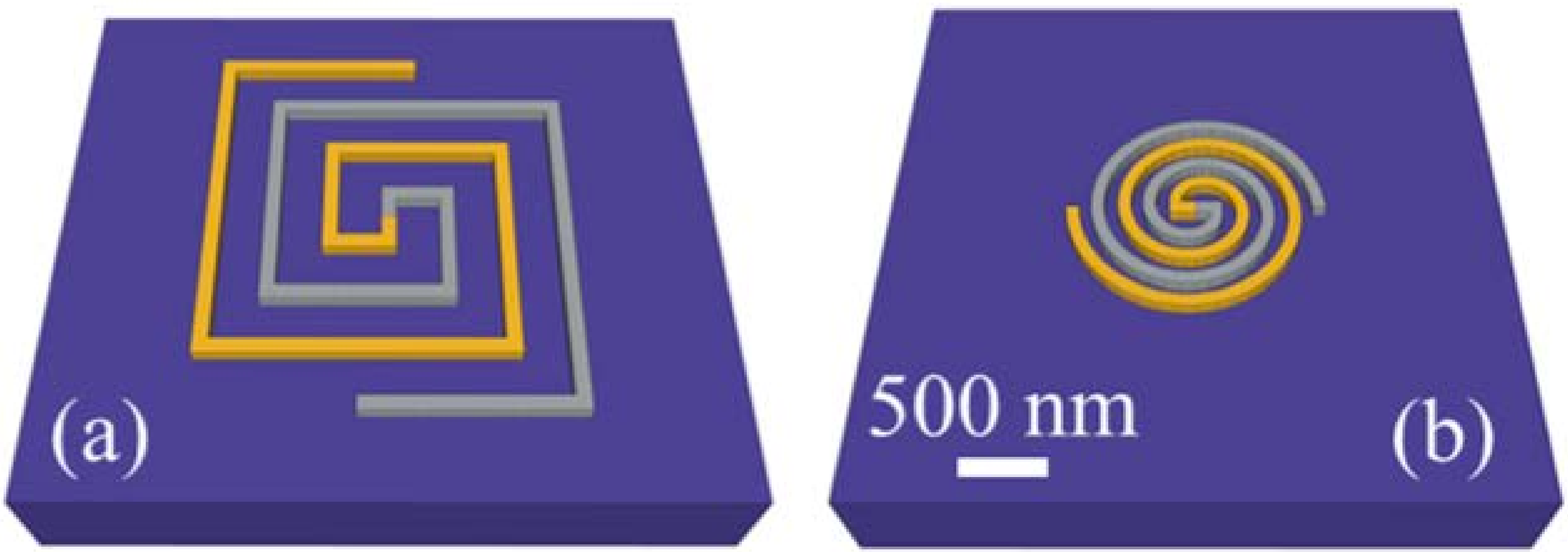
Single-metal nanothermocouples



The hot and cold junctions of the thermocouple are formed between the narrow and wide wire segments. Fabrication complexity is greatly reduced compared to bi- metallic thermocouples, and might point the way to large-scale fabrication.

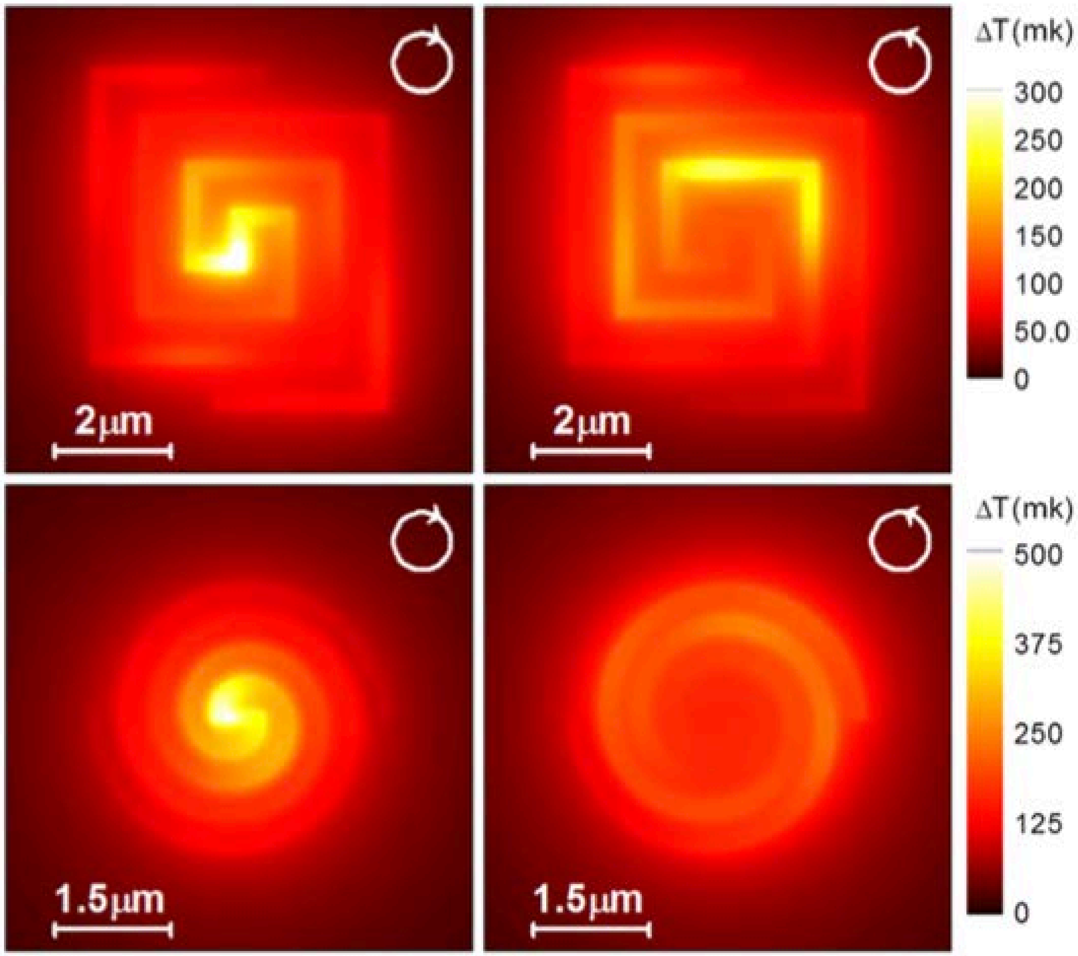
G.P. Szakmany, P.M. Krenz, A.O. Orlov, G.H. Bernstein, W. Porod, "Nanoantenna Integrated Infrared Thermoelectric Converter," Proceedings of the 14th IEEE International Conference on Nanotechnology Toronto, Canada, August 18-21, 2014

Seebeck Nanoantennas



E. Briones, A. Cuadrado, J. Briones, J.C. Martínez-Antón, S. McMurtry, M. Hehn, F. Montaigne, J. Alda and **F. J. González,** "Seebeck nanoantennas for solar energy harvesting," *Applied Physics Letters*, *105, 093108, (2014)*.

Seebeck Nanoantennas



Materials:

Ti/Ni (S_Ni = -15, S_Ti =7.19)

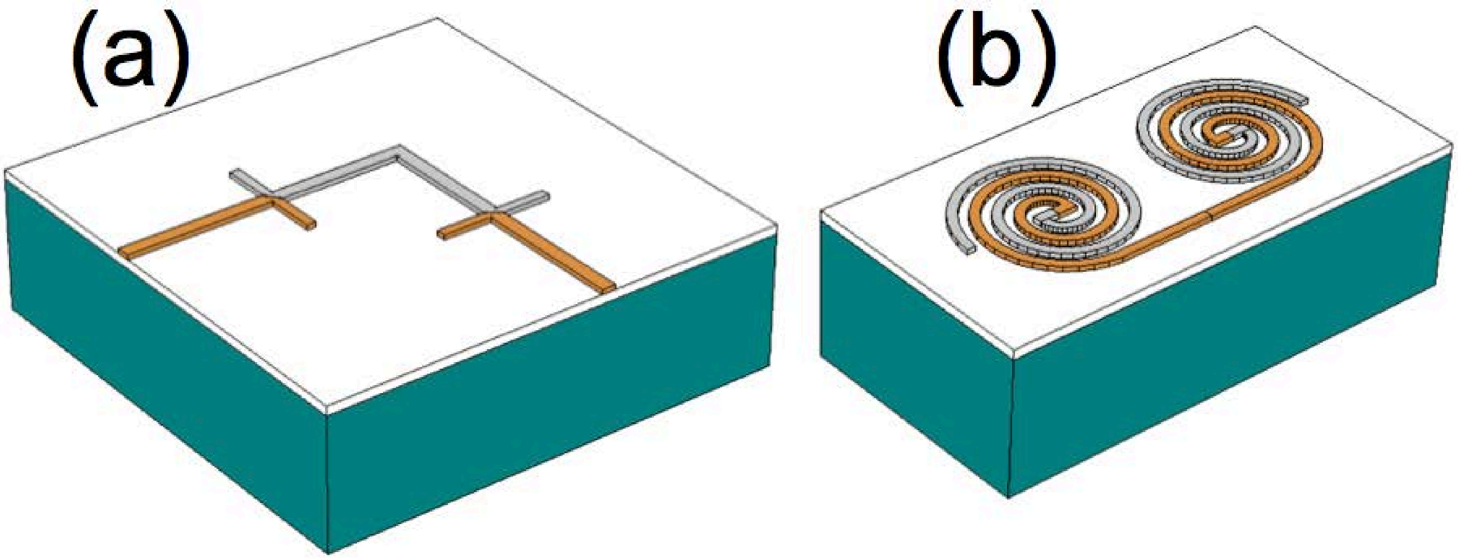
ΔV= 5.74 μV

ΔV= 9.08 μV

E. Briones, A. Cuadrado, J. Briones, J.C. Martínez-Antón, S. McMurtry, M. Hehn, F. Montaigne, J. Alda and **F. J. González,** "Seebeck nanoantennas for solar energy harvesting," *Applied Physics Letters, 105, 093108, (2014).*

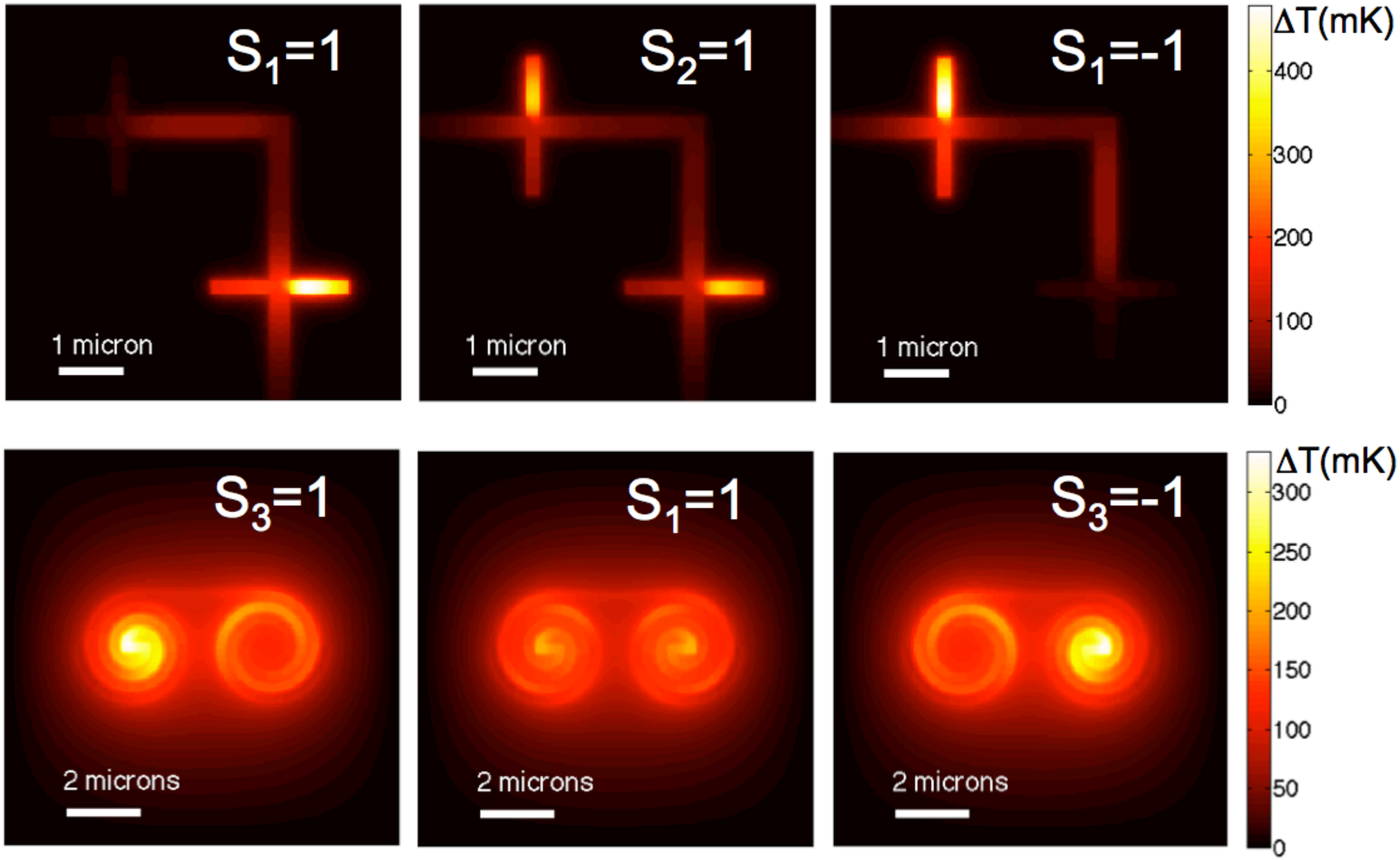
Other Applications

Polarization detection



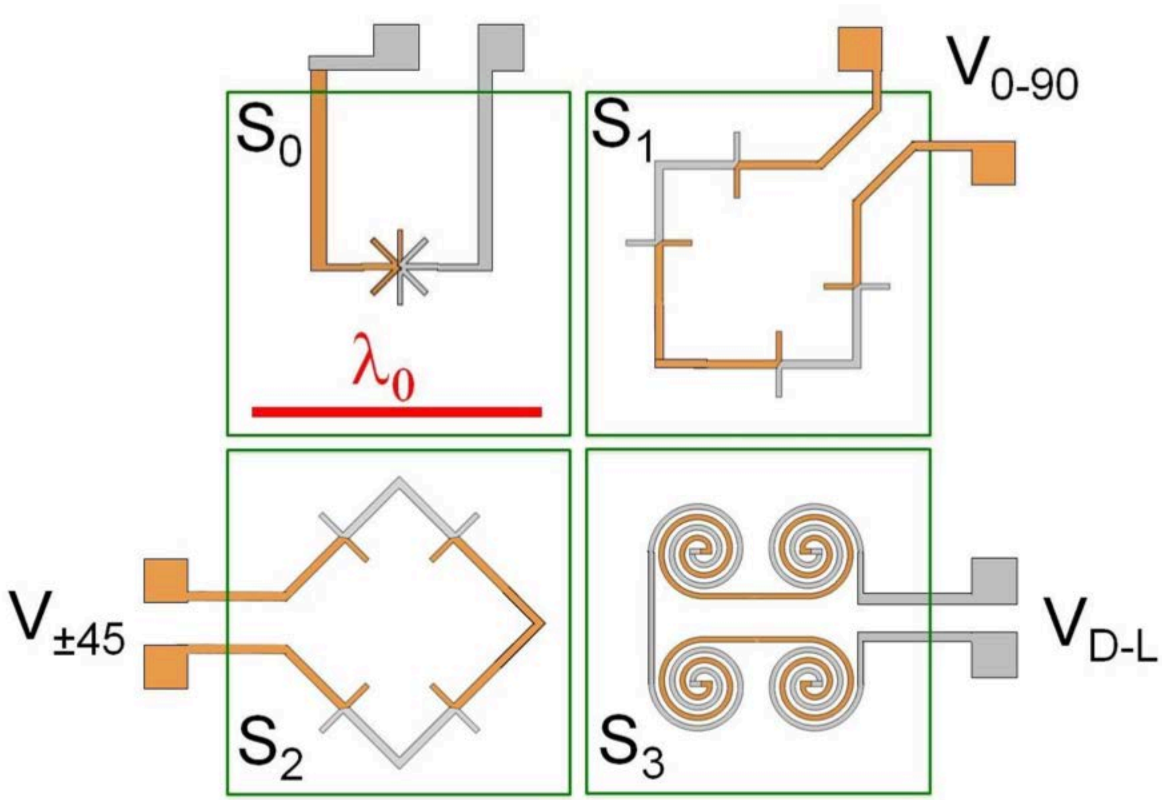
A. Cuadrado, E. Briones, **F. J. González** and J. Alda, "Polarimetric pixel using Seebeck nanoantennas," *Optics Express, 22 (11), pp.13835-13845, (2014)*

Polarization detection



A. Cuadrado, E. Briones, **F. J. González** and J. Alda, "Polarimetric pixel using Seebeck nanoantennas," *Optics Express, 22 (11), pp.13835-13845, (2014)*

Polarization detection



A. Cuadrado, E. Briones, **F. J. González** and J. Alda, "Polarimetric pixel using Seebeck nanoantennas," *Optics Express, 22 (11), pp.13835-13845, (2014)*

New Fabrication Methods

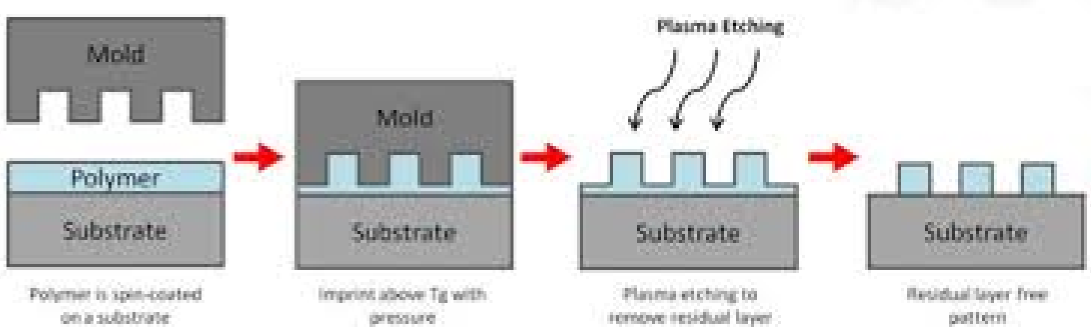
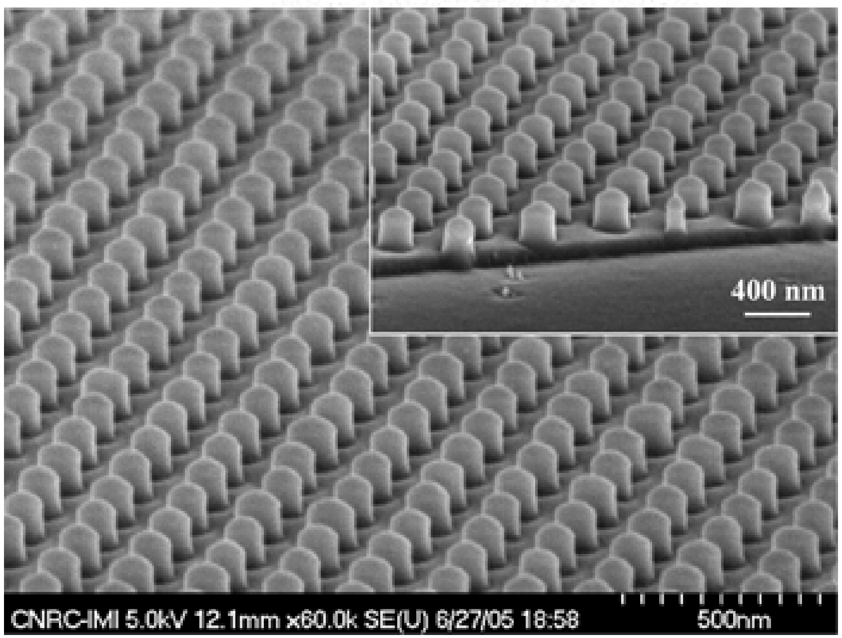
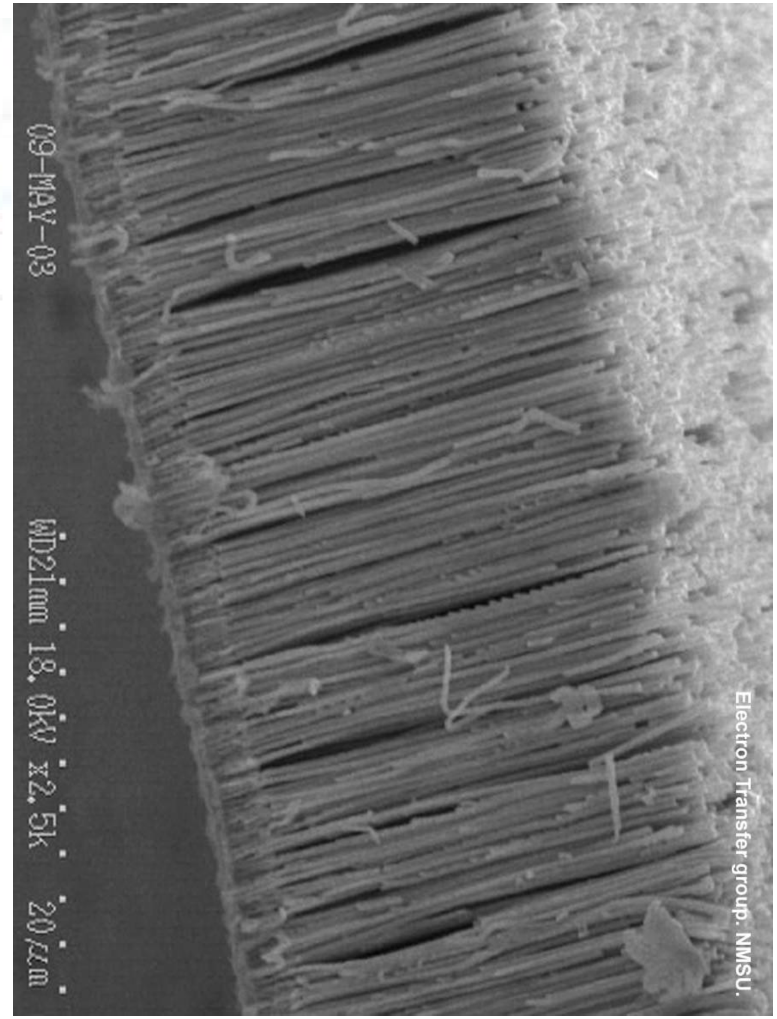


Figure 1: Basic NIL hot embossing process



Nanoimprint Lithography



Electrochemical deposition

Conclusions

- Antenna-coupled microbolometers can be used for infrared detection and can be integrated into ROICs to make IR-FPA.
- Rectennas would probably have extremely low efficiencies making them impractical for energy harvesting applications.
- **Nanoantennas can be used to harvest solar energy by using them in a Seebeck-Nanoantenna configuration.**
- Measurements will show what would be the real efficiency of this devices and would indicate the possible applications.

Collaborators

Prof. Glenn Boreman
(UNCC)

Prof. Javier Alda
(UCM)